DOCTOR OF PHILOSOPHY

Marine Invasive Species in the Galapagos Marine Reserve

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Award date:
2016

Marine Invasive Species in the Galapagos Marine Reserve

By

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Thesis submitted in fulfilment of the requirement for the degree of Doctor of Philosophy (PhD)

University of Dundee

United Kingdom

January 2016

Table of contents

List of figures

List of tables

Acronyms

ABG	Agencia de Regulación y Control de la Bioseguridad y Cuarentena para Galápagos
CDF	Charles Darwin Foundation
CDRS	Charles Darwin Research Station
CGREG	Consejo de Gobierno de Régimen Especial de Galápagos
DPNG	Dirección del Parque Nacional Galápagos
ENSO	El Niño Southern Oscillation
ETP	Eastern Tropical Pacific
FCD	Fundación Charles Darwin
GMR	Galapagos Marine Reserve
GNP	Galapagos National Park
INOCAR	Instituto Oceanográfico de la Armada
LOREG	Ley Orgánica Régimen Especial de Galápagos
MAE	Ministerio del Ambiente del Ecuador
MSP	Ministerio de Salud Publica
MTOP	Ministerio de Transporte y Obras Publicas
Senplades	Secretaria Nacional de Planificación y Desarrollo
SERC	Smithsonian Environmental Research Center
SPTMF	Subsecretaria de Puertos y Transporte Marítimo y Fluvial
STRI	Smithsonian Tropical Research Institute

Acknowledgements

I would like to express my special appreciation and thanks to my PhD supervisors Professor Terry Dawson and Dr Ken Collins who have been incredible during these three years. I would like to thank you for encouraging my research, for allowing me to grow as a research scientist and for sharing all the amazing field trips in the Galapagos and the academic time in the UK.

I wish to thank Darwin Initiative, Galapagos Conservancy, Lindblad Expeditions – National Geographic, The Rufford Foundation and World Wide Fund for Nature for the funding provided that allowed me to complete this research, without them it wouldn't have been possible.

A big thank you to the Charles Darwin Foundation and the Charles Darwin Research Station for supporting me during my research and allowing me to be part of a great team that works hard to ensure the conservation of the Galapagos Islands.

Thank you to the Galapagos National Park Directorate (DPNG), the Galapagos Biosecurity Agency (ABG), the Ecuadorian Navy and the Oceanographic Institute (INOCAR) for the collaboration extended by the institutions and the technicians.

I would also like to thank many new friends that I have met during this research and that have become collaborators in my research. Dr Jim Carlton, Dr Linda McCann, Dr Greg Ruiz, Dr Mark Torchin, Dr Chad Hewitt and Dr Marnie Campbell. I would also like to thank the 'Queen Mabel'and its crew for all the great field trips around the archipelago.

I also thank my friends (you know who you are!) for providing support and friendship and for always having good laughs no matter where I am.Thank you to

my family in Scotland whohave made me feel very welcome on every visit and a verybig and special thank you to my parents for their constant love and support and for always believing in me.

Declaration

I hereby confirm that this thesis and the work presented in it are my own and it has been generated by me as the result of my own original research.The author has consulted all references cited in this thesis. The material contained in the thesis has not been previously submitted for a higher degree in this or any other institution.

Inti Keith

Abstract

Marine biological invasions have increased significantly in recent years due to global trade, transport and tourism. Invasions occur when species get transported from one region to another and establish themselves in the new habitat. These species compete for space and resources, displacing native species and changing, populations and communities. Invasive non-native species are the number one threat to Galapagos ecosystems and although many preventive and corrective measures have been applied to terrestrial problems, the impacts of invasive non-native species in the marine environment has received relatively little attention to date. The marine ecosystems of Galapagos harbour distinctive biological communities given a unique confluence of currents in the Eastern Tropical Pacific (ETP). They sustain a high incidence of endemic species, which are regularly subjected to extreme climate variability through El Niño–Southern Oscillation (ENSO) events. This research examines the negative impacts that marine non-native species can have on the biodiversity, ecosystem services and the health of the Galapagos Marine Reserve (GMR). Baseline surveys revealed nine marine non-native species present in the GMR at this time and the potential for the impacts of high-risk species for the GMR examined. Furthermore international marine traffic was analysed resulting in Panama and Guayaquil being identified as the hotspots for the translocation of marine no-native species to the Galapagos. A species based exposure model produced a list of 469 high-risk species that could have arrived in the GMR during 2013 from 14 different regions worldwide. Additionally, natural vectors were assessed as well as natural processes enhanced by anthropogenic activity. These results reflect the considerable risk that these vectors pose in the translocation of marine non-native species, furthermore ENSO events and global climate change were identified as major threats to the marine ecosystems of the GMR due to the increase in SST. Species distribution models are presented for 19 high-risk non-native species and the open niche scenario is described as the biggest threat the GMR is facing with the arrival of non-native species regardless as

to how these species arrive through anthropogenic or natural vectors. Several risk assessments are presented and discussed in order to provide management strategies for decision makers in the GMR.

Chapter 1:

Introduction

1.1 Research context

The introduction of invasive non-native species is considered the second most important reason for biodiversity loss worldwide after habitat destruction, and in oceanic islands, they are the greatest threat (Altman & Whitlach, 2007; IUCN, 2015; Mack *et al.* 2000; Parker *et al.* 1999; Park, 2004; Park, 2004;Vitousek *et al.* 1996). Biological invasions have increased during the last decades, mostly due to the accelerated spread of species caused by growing global trade, transport, and tourism overcoming natural barriers, such as currents, land masses, and temperature gradients that once limited the movement of species (Carlton, 1996; Seebens *et al*. 2013; Hilliard, 2004). Marine bioinvasions are currently recognised as a problem throughout the world's oceans, with human beings having moved species beyond their native ranges for many years, whether deliberately or not, and some of these species have managed to establish and proliferate causing significant ecological, economic and health impacts (Campbell & Hewitt, 2013;Vitousek *et al.* 1997).Marine invasive species can cause many environmental impacts such as loss of native biodiversity, changes to ecosystem functions, changes to nutrient cycles, decreased water quality, sedimentation and displacement of native species (Bax *et al.* 2003; De Poorter, 2009; Molnar *et al*. 2008).

Several anthropogenic vector categories exist including shipping (hull and ballast), aquaculture, marine debris amongst others. Marine traffic is a major vector, where shipping vessels can act as biological islands for species that live in harbours around the world (Wonham *et al.* 2001). As ships transit or anchor in these areas, some species colonise their sub-surface areas and hitch a ride. These vessels provide places for the settlement of species associated with fouling communities. They can provide protected spaces where both sessile and mobile fauna can settle and enclosed spaces that hold water in which a wide range of organisms can travel

(Godwin, 2003; Wonham *et al.* 2001). Maritime traffic plays a crucial role in the spread of non-native species because many of these organisms can be moved between regions by commercial and recreational vessels (Hulme, 2009; Kolar & Lodge, 2002;). Other non-anthropogenic vectors exist that can naturally disperse marine organisms throughout the world including, current systems, climate variations, migrating species, and natural phenomena, like significant storm events. However, another vector that has been identified in recent years is marine debris. The possibility has been explored that marine species can adhere themselves to floating waste and can be transported thousands of miles to different bioregions (Chan, 2012). This research focuses on marine non-native species in the Galapagos Marine Reserve (GMR) and the impacts these species could cause to the native biodiversity of the marine realm. The Galapagos Islands are located off the coast of Ecuador in the Eastern Tropical Pacific (ETP) and are home to the GMR. The Galapagos Islands sustain a high incidence of endemic species, which are subjected to extreme climate variability through El Niño Southern Oscillation (ENSO) events (Hickman, 2009).

The geographic isolation of the Galapagos Islands has limited immigration of new species historically enabling those few species that did arrive to evolve in the absence of competitors and predators. For this reason, oceanic islands are more prone to the impacts of invasive non-native species because of the paucity of natural competitors and predators that control populations in their native ecosystem. Islands often have ecological niches that have not been filled because of the distance from colonizing populations, increasing the probability of successful invasion (Loope *et al.* 1988).

The impacts of terrestrial invasive non-native species have been studied extensively in the Galapagos Islands, with the consequence that there are now strict control and quarantine protocols to prevent the entry of terrestrial introduced species (Zapata, 2006). TheAgencia de Regulación y Control de la Bioseguridad y Cuarentena para Galápagos (ABG) is the Galapagos Biosecurity Agency created in 2012. This agency is in charge of controlling, regulating, preventing and reducing the risk of the introduction, movement and dispersal of non-native organisms that might threaten human health, the terrestrial and marine ecosystems, the integrity of the islands and the conservation of biodiversity of the Galapagos Province (ABG, 2015). While research on terrestrial invasive species such as mammals, birds, plants and insects is well established, research conducted on marine invasive species and the impacts to the Galapagos Marine Reserve is sparse (Campbell *et al.* 2015). The management of marine invasive species presents more challenges than terrestrial invasive species due to the high degree of natural connectivity that exists and the logistics required to work in the marine environment.

The GMR is under threat from possible marine non-native species arrivals, given the connectivity that exists with the ETP, the increase in tourism and associated marine traffic and the effect of extreme climatic events such as the ENSO. This type of event brings unusually warm water across the central and east-central equatorial Pacific, giving opportunistic non-native species a window of opportunity to move into new ecosystems and outcompete native and endemic species (Hickman, 1998).

This thesis has established a baseline of non-native marine species in the GMR and examined the various vectors that facilitate the transport of potentially aggressive non-native species to the islands, and produced management strategies in collaboration with local authorities. A list of high-risk non-native species for the GMR has been assembled based on marine traffic, climate models and literature searches. Species like the white coral *Carijoa riseii* that has already been reported in continental Ecuador and the island of Malpelo, Colombia, could be transported and cause detrimental impacts to the marine ecosystems of the GMR. It is a priority to establish what the high-risk non-native species are for the GMR to improve management protocols for marine invasive species. Prevention, early detection and rapid response protocols have to be put in place along with risk assessments and management strategies to mitigate negative impacts of those species.

1.2 Aims of the research

The principal aim of this thesis is produce a baseline study for marine non-native species in the GMR and evaluate the potential impacts that marine non-native species can have on the biodiversity, ecosystem services and the health of the GMR. Secondly, the research aims to investigate thow marine traffic, oceanic currents and climate change in the ETP region could influence the translocation of non-native species to the GMR. Finally, the study aims to develop a biosecurity plan for the GMR to enable control measures in collaboration with local authorities.

1.2.1 Objectives of the research

1. Review of existing literature on marine invasive species worldwide focusing on vectors and pathways of dispersion, natural means of dispersion and negative impacts on biodiversity, ecosystem services and the health of the GMR.
2. Create a baseline of marine non-native species in the GMR.
3. Assess the movements of marine traffic in the ETP and the Galapagos Islands. Evaluate where the marine traffic is coming from and where the main hotspots are for the transfer of marine invasive species.
4. Assess the natural vectors that can cause secondary spread of marine non-natives to the Galapagos Marine Reserve and study the impacts these can cause on marine ecosystems.
5. Using Species Distribution Models predict the risk of specific non-native species reaching the GMR
6. Develop management strategies to help local stakeholders manage a possible invasion of non-native species in the Galapagos Marine Reserve.

1.3 Chapter overview

The framework illustrated in Figure 1.1 introduces this thesis and displays each chapter and how they are related to each other. The thesis consists of nine chapters, a brief summary of each follow the framework.

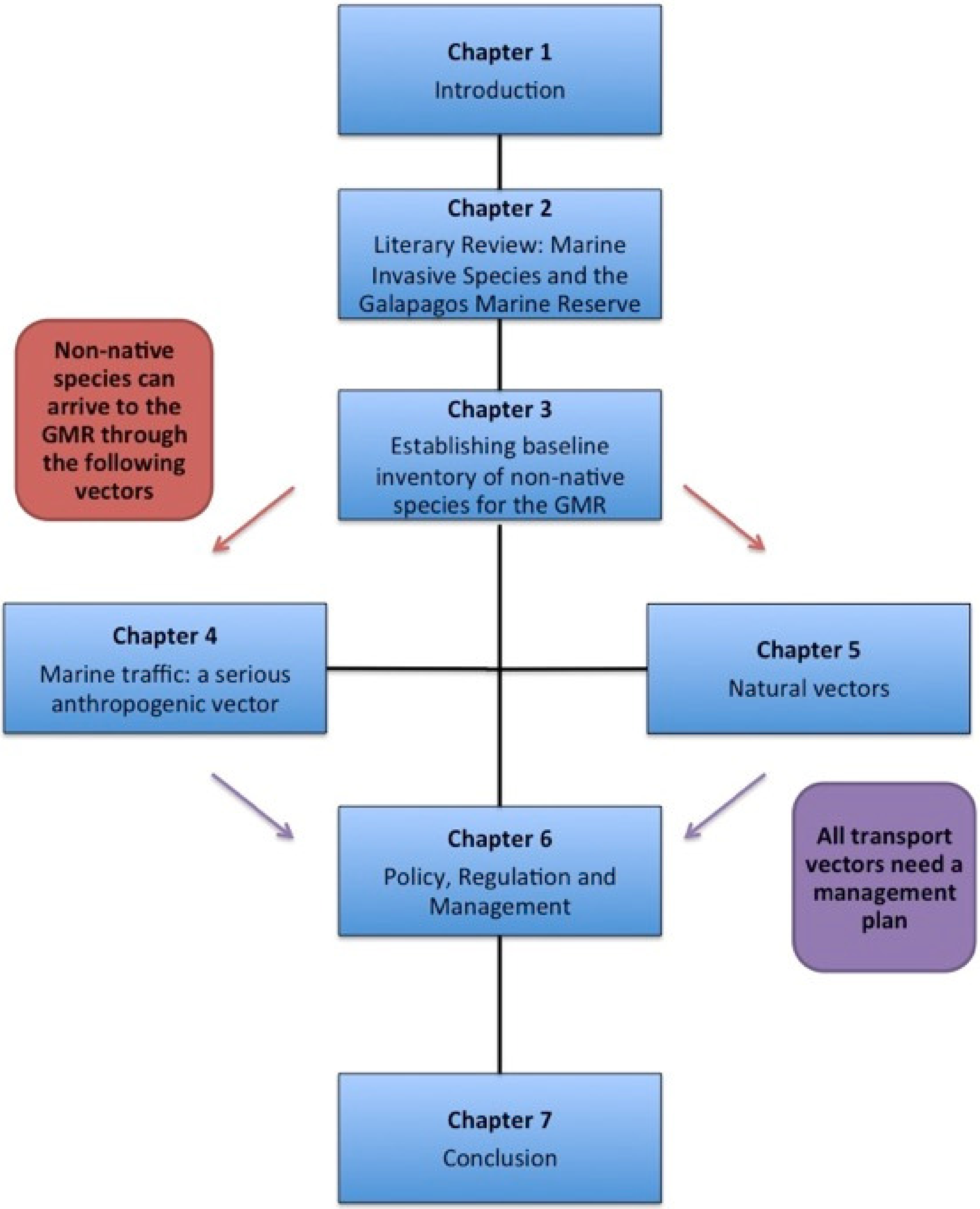


Figure 1.1: This framework illustrates the association between all the chapters in this thesis.

1.3.1 Chapter summaries

The following section outlines summaries of each chapter of this thesis as well as illustrating where the information has been published throughout the research for this thesis (peer reviewed journals, technical reports, international conferences). A complete list can be seen in Appendix I.

Chapter 2

This chapter provides background information of the location of the Galapagos Islands and the GMR. The chapter describes the terminology used in the literature and continues by explaining the process of invasion, comparing the terrestrial invasion process to that of the marine realm. An overview of vectors and pathways are described by looking at marine traffic, climate change and ocean connectivity connecting these topics to the Galapagos Islands. Additionally examples of some problematic marine invasive species worldwide are described illustrating the impacts and cost of control and/or eradication.Finally, this chapter provides a list of marine non-native species established in the GMR, and when they were reported in the literature as well as an initial list of potential non-native species that could arrive to the GMR, additionally a brief description and current distribution of each of these species can be found.

Chapter 3

An overview of the research methodology used in this thesis is described in this chapter. It discusses the historical monitoring that has been conducted in the GMR, followed by the several different marine surveys used in this research in order to provide a baseline of which marine non-native species are present in the GMR at this time. The results of the marine surveys are described in this chapter showing the baseline of marine non-native species present in the GMR and their distribution around the archipelago. An overview of each species is illustrated in the form of a fact sheet describing the species, its habitat, the possible impact and current distribution. Additionally, the impacts these species are having on the marine ecosystems are examined, and management strategies are discussed.

Chapter 4

This chapter introduces possible vectors for the GMR and begins by describing the different types of marine traffic that arrive in the islands, where the traffic comes from, and the risks associated with each are examined. Marine traffic data is analysed throughout this chapter, and a risk assessment is conducted. A species-based exposure analysis was used to assess the risk of marine traffic introducing biofouling organisms to the GMR and a consequence matrix was implemented in order to see what core values could be affected by these species.

Chapter 5

Continuing with vectors that could transport marine non-native species to the GMR, this chapter examines natural vectors. It describes natural dispersion through connectivity in the Eastern Tropical Pacific and climate variability as well as natural processes enhanced by anthropogenic activity such as climate change and marine debris. Additionally, a Species Distribution Model was used to predict non-native species range expansion, and the open niche scenario is discussed.

Chapter 6

An overview of policy, regulations and management of marine invasive species is described in this chapter by looking at the Ecuadorian Government environmental policy and how the research conducted in this thesis fits into the current policy. Additionally, this chapter describes management strategies through biosecurity action plans that were conducted in this research and concludes by discussing the BowTie risk assessment method and how this could be applied to assess the risk of arrival of marine non-native species to the GMR.

Chapter 7

The conclusion chapter of this thesis draws together the main points from the discussion sections in each chapter and presents management recommendations for the prevention of marine non-native species arriving to the GMR. The strengths and weaknesses of this research are discussed along with future research recommendations in order to advance in this field.

Chapter 2:

Literature Review – Marine Invasive Species and the Galapagos Marine Reserve

2.1 Introduction

The Galapagos archipelago is located 1,000 km off the coast of Ecuador in the ETP (Figure 3.1).The archipelago is a volcanic hotspot that consists of 13 large islands and over 100 smaller islands, islets, and rocks (Sachs & Ladd, 2010). This oceanic archipelago is home to two important Natural Heritage Sites, the Galapagos National Park (GNP) created in 1959 and the GMR created in 1998 with the Special Law for the Conservation and Sustainable Development of the Galapagos Province (LOREG, 1998). The GMR extends to a distance of 40 nautical miles out from the coastal baseline that surrounds the archipelago, creating a protected area of about 138,000 km^2 (Danulat & Edgar, 2002). The Galapagos Islands are renowned for their unique biological diversity, high levels of endemism, and the unique currents and oceanographic features that allow a variety of habitats to exist (Hickman, 2009). The archipelago is influenced by a number of major surface and submarine current systems and are characterized by a diverse wildlife compared to other islands, with representatives corresponding to the Indo-Pacific, Panama, and Peru regions of the Pacific (Muromtsev 1963; Banks, 2002; Hickman, 2009). Studies have shown, however, that marine ecosystems in the Galapagos are sensitive to climate change and not well adapted to extreme thermal impacts (Edgar *et al.* 2010).

The number of terrestrial and marine species introduced to the Galapagos archipelago has increased by orders of magnitude in the past 100 years. The impacts of terrestrial invasive species have been studied extensively (Zapata, 2006) but unfortunately this is not the case for the marine environment at present. Examples of high potential invasive species such as *Caulerpa racemosa* and *Asparagopsis taxiformis* are already established in the GMR (Keith *et al.* 2013). Also there are several species with a high potential to be introduced to the islands, such as white coral *Carijoa riisei* that has already been reported in continental Ecuador and in the island of Malpelo, Colombia (Sanchez *et al.* 2011), located 500 km west of continental Colombia and about 1200 km north-west from the Island of Darwin in the GMR (Figure 2.1). This invasive species is characterised by successfully competing for space and resources against other native or endemic algae and corals.

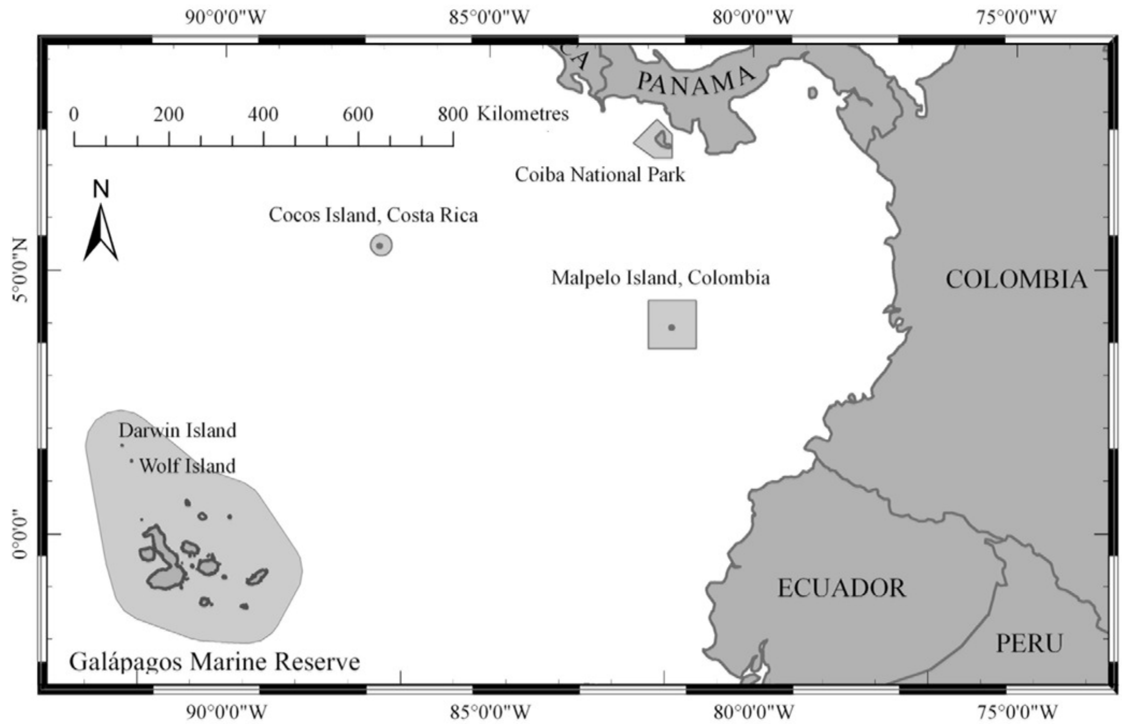


Figure 2.1: Map illustrating the location of the Galapagos Islands in the Eastern Tropical Pacific (Banks *et al*. 2009)

2.2 Biological invasions

Biological invasions occur when a species enters a new environment, establishes and changes the population that existed there before, disturbing the balance of plant and animal communities (Emerton & Howard, 2008; Williamson, 1996). Terms and concepts crucial to understanding invasive ecology have often been criticized for their repetitive, ambiguous or non-operational nature (Colautii & MacIssac, 2004). The terms alien, invasive, non-native, exotic amongst others have caused confusion over the years and have been highlighted in several publications (Colautii & MacIssac, 2004; Davis & Thompson, 2000; Emerton & Howard, 2008;

Hilliard, 2004; IUCN Council, 2000; Kolar & Lodge, 2001; Richardson *et al.* 2000; Ruiz *et al.* 2000; Walther *et al.* 2009).

Invasive non-native species can cause damage to the biological productivity, habitat structure, species composition as well as economic and health problems (IUCN, 2013). The term alien refers to an organism occurring outside its natural range and dispersal ability, whose presence is due to intentional or unintentional human action (Walther *et al.* 2009). In contrast, invasive alien species are animals, plants or other organisms introduced by man into places out of their natural range of distribution, where they become established and disperse, generating a negative impact on the local ecosystem and species (IUCN, 2015). The term invasive is the subset of introduced and refers to established alien organisms that are rapidly extending their range in a new region causing significant harm to biodiversity, ecosystem functions, socio-economic values and human health in invaded regions (Walther *et al.* 2009).

The term introduced defines plants and animals that have been intentionally or accidentally introduced by human activity (Hilliard, 2004; IUCN, 2015). Species can also be translocated through natural events, mostly through changes in environmental conditions, these species are referred to as natural arrivals. Species that are introduced or that have arrived naturally are not necessarily invasive; in fact, many species have features that allow them to establish in a new habitat and/or are temporary visitors, without any discerning effect on the existing communities, however very different to measure (Ojaveer *et al.* 2015)However, some species have a greater capability to establish in a new habitat outside their natural distribution range and can change diversity and local ecosystems (De Poorter, 2009; Hilliard, 2004; IUCN, 2015). If such species can adapt to new environmental conditions and multiply, they can become a threat to native species, affecting ecosystem resources such as fisheries or species of importance to tourism, changing ecosystem functioning and processes and altering the ability of the ecosystem to recover against climate events such as El Niño.

Marine bioinvasions are currently recognised as a widespread issue throughout the world's oceans with significantly recognised impacts to the environment, the economy and health (Campbell & Hewitt, 2013). There are several vectors that allow marine species to make their way around the world. World maritime traffic has increased exponentially in the last decades by globalisation processes: increasing trade, transport, travel and tourism (McNeely, 2001). This has led to traditional natural barriers that existed in the past being broken, and marine species have been transported beyond their natural range causing serious damage to different ecosystems. Another problem that exists is the lack of basic information about the inventory of species present in the different regions of the world. It is very easy for a new invasion to occur due to the connectivity of oceanic currents that exists and the lack of control measures that exist. Although there has been some successful eradication of marine invasive species, it is clear that it is much better and more cost effective to prevent an invasion rather than try to eradicate the species once it is established.

2.3 Invasive species – introduction, establishment, dispersal

IUCN in their Marine Menace bulletin (De Poorter, 2009) have an interesting quote for marine invasive species. "Any alien species should be considered guilty unless proven innocent". However not all alien species become invasive and predicting which ones will do so remains a problem. Species that at first may seem to establish and not behave in an invasive manner can change and become invasive under the right environmental conditions (De Poorter, 2009). Hence, the need to consider alien species "guilty unless proven innocent."

2.3.1 Understanding invasive species

The understanding and management of marine bioinvasions is a developing science, and its terminology continues to evolve and change. Presently there is no convenient, widely referenced glossary of terms that provides an integrated set of consistent, logical definitions based on fully understood processes (Hilliard, 2004). The use of simple terms to articulate ecological concepts can confuse and undermine management efforts. This problem is particularly acute in studies of non-native species, which alternatively have been called 'exotic', 'introduced', 'invasive' and 'naturalised', among others (Colautti & MacIssac, 2004).

Humans have moved species beyond their native ranges for many years, be it deliberately or not, and some of these species manage to establish and spread causing significant ecological and economic problems (Vitousek *et al.* 1997). Globally, the list of established introduced species grows annually and with it, the different definitions of what an invasive species is. Alien species have colonised virtually every ecosystem type on Earth and affected the native biota and have contributed to the local and global extinction of hundreds of species (Vitousek *et al.* 1996; IUCN Council, 2000).

The terms set out in Table 2.1 are commonly used and described in several publications including (Colautti & MacIsaac, 2004; Hilliard, 2004; Emerton & Howard, 2008; Kolar & Lodge, 2001; Richardson *et al.* 2000; Ruiz *et al.* 2000; IUCN Council, 2000). Terms like Alien species, Invasive species and Non-native species/ non-indigenous species (NIS) are used interchangeably and often without noting the difference between them (Mack *et al.* 2000) causing confusion and obscuring how these species behave and spread. There have been several discussions about all these terms in recent years but at the Convention on Biological Diversity (51st Meeting of the IUCN Council, 2000) it was concluded that an invasive alien species or a non-native was defined as an agent of change that threatens native biological diversity (Emerton & Howard, 2008; IUCN Council, 2000).

Table 2.1: Key definitions for non-native species.

Non-native species/ non-indigenous species (NIS)	A species introduced to areas beyond its native range by direct or indirect human activity, intentionally or otherwise (Richardson *et al.* 2000; Kolar & Lodge, 2001; Hilliard, 2004; Ruiz *et al.* 2000) These are more precise terms than some ambiguous terms such as adventive, alien, exotic, feral, foreign, invasive, ornamental or weedy species (Hilliard, 2004).
Invasive species	A non-indigenous species that spreads from one point of introduction and becomes abundant (Richardson *et al.* 2000; Kolar & Lodge, 2001).
Alien Species	A species that has been introduced to a location where it does not normally occur (Emerton & Howard, 2008). A species, subspecies, or lower taxon occurring outside of its natural range

	and dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans) and includes any part, gametes or propagule of such species that might survive and subsequently reproduce (IUCN Council, 2000).
Alien invasive species (non-native, non-indigenous, foreign, exotic)	A species that causes or has the potential to cause harm to the environment, economies and/or human health. (Emerton & Howard, 2008). An alien species that becomes established in natural or semi-natural ecosystems or habitat is an agent of change and threatens native biological diversity (IUCN Council, 2000).

2.3.2 Process of invasion

The study of invasive biology has defined the stages a species must go through to become invasive, and these are (i) Introduction, (ii) Establishment, (iii) Spread and Naturalisation or (iv) Spread and Invasion (Emerton & Howard, 2008). A lot of research has been conducted on terrestrial environments, and a lot of what has been learned can be applied to the marine environment. The process of plant invasions occurs when an introduced plant species arrives into a new region, this can be divided into three phases: Introduction, Colonization and Naturalization (Richardson *et al.* 2000). The arrival and establishment of an introduced plant species can be through the deliberate human introduction or accidentally as hitchhikers, these species can become benign additions, or they can dominate the community (Henderson *et al.* 2006; Richardson *et al.* 2000). The dispersal of a terrestrial plant can occur through several patterns of dispersal that can cause different outcomes (Henderson *et al.* 2006). An introduced species is considered invasive if it tolerates a range of local environmental conditions, forms a common component of the habitats and communities into which it spreads, and/or colonises a relatively wide geographical area (Hutchings *et al.* 2002; Ruiz *et al.* 1997). Once the introduced species establishes and spreads it can gain the term 'Invasive species' depending on the type and extent of disruptions it may cause.

Non-native species have transformed marine habitats around the world. The most harmful of these non-native species displace native species, change community structure and food webs, and alter fundamental processes, such as nutrient cycling and sedimentation (Molnar *et al.* 2008). The unintentional transfer of species by human activities is the main driving force of invasions (Carlton & Ruiz, 2005).Species have been relocated around the world as a result of a larger, wealthier, globalized human population. The growth of population and wealth worldwide and the breaking of natural barriers combined with the increase of international commerce and transport results in species being relocated (Henderson *et al.* 2006). It is therefore very important to look at how species are relocated from one region to another what vectors and pathways are used and how these species manage to establish and what can be done to prevent this happening. Once alien species become established in marine habitats, it can be nearly impossible to eliminate those (Thresher & Kuris, 2004). Interception or the removal of pathways is probably the only effective strategy for reducing future impacts (Carlton & Ruiz,2005).

Propagule pressure or introduction effort is the measure of the number of individuals released into a region to which they are not native. The success or failure to establish in a new environment depends on the multi-step process of non-native invasion (Lockwood *et al.* 2005). Non-native species arrive in new areas as hitchhikers by unintentional introductions due to trade, travel and transport and in some cases, species move through man-made canals. In contrast there can be intentional introductions of non-native species, in some cases, these are planned introductions as part of bio-controls or management. A more serious side to intentional introduction are the introductions that are planned and contained, but the non-native species often escapes. (e.g. mariculture, aquariums, live seafood trade and live fish bait trade) (De Poorter, 2009). In terrestrial environments it is often said that invasions happen more readily in disturbed sites than elsewhere, it is thought that it is more likely that species will be transported and arrive at disturbed sites because of human activity.In the marine environment this is not the case, the focus is not on the disturbance area it is on the origin of invaders, the mode of transport and the character of the invaded place (Williamson, 1996). For a non-native species to successfully invade the species must be transported out of its native range and released in a new location, it must establish a self-sustaining population and expand its geographic range beyond the point of initial establishment (Lockwood *et al.* 2005) (Figure 2.2). The following are rules applied to terrestrial plants and animals, but the same concepts can be applied to marine species. Once a species has been introduced the success of establishment is closely correlated with propagule pressure and the 'tens rule' (Henderson *et al.* 2006). The strength of the relationship between propagule pressure and establishment success does not take away the importance of location and species although it is the interaction of these factors with propagule pressure that might be the most important element to furthering understanding invasions (Lockwood *et al.* 2005).

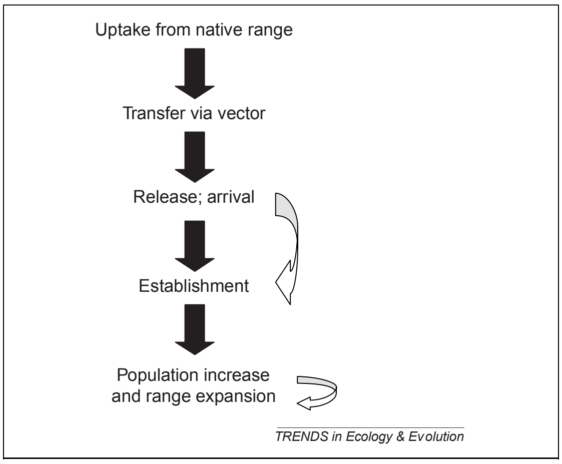


Figure 2.2: Process of non-native species invasion. Black arrows indicate transitions: White arrows indicate the propagule pressure (Lockwood *et al.* 2005).

The tens rule states that the statistical rule holds 1 in 10 of those introduced species appear in the wild, 1 in 10 of those introduced become established and 1 in 10 of those established become invasive. No statistical rule is exact which is why the tens rule has a confidence interval of 5-20% (Williamson & Fitter, 1996). This means that the chance of an introduced species becoming invasive is around 0.1%. Taking these concepts and applying them to the marine environment would result in three sets of factors. The first would consist of the propagule pressure, the rate at which propagules or breeding individuals are released. The second is the set of factors that allow species to survive, and increase, from low densities. The third is the set of factors that determine local abundance (Williamson & Fitter, 1996).

The relationship between propagule pressure and invasion success is very important to consider when looking at conservation (Lockwood *et al.* 2005;

Henderson *et al.* 2006). Regarding invasion success, the following is an explanation of the different situations that can occur with propagule pressure. The release of large numbers of individuals will help the early non-native population survive the decrease in survival or reproduction caused at a new location. A repeated release of individuals into one location increases the chances of establishment by sustaining a developing population even though the first release was not sufficient in establishing. On the other hand, large or consistent releases of individuals into one location should enable the developing population overcome any problems associated with small population sizes. The amount of genetic variation in the introduced population can improve the chances that the population will adapt. Another way a population can ensure establishment is with spatially timed releases in order to find favourable environmental conditions (Lockwood *et al.* 2005).

2.4 Vectors and pathways

A vector is the physical means, agent or mechanism, which facilitates the transfer of organisms or their *propagules* from one place to another (Campbell & Hewitt, 2013; Hilliard, 2004; Hewitt & Hayes, 2002). Marine organisms need mechanisms or vectors in order to move from their native region to another (Hewitt & Hayes, 2002). Several categories exist when naming vectors some include the following: Shipping (hulls, ballast water, dry ballast, anchors, etc), fisheries (intentional and unintentional release), biocontrol, ornamental escape, agricultural escape, research escape and man-made canals where organisms can swim or float through from one area to another (Ruiz *et al.* 2000). Similarly (Godwin, 2003) talks about the anthropogenic influences that have occurred with the transport of species through a variety of mechanisms including maritime shipping, live seafood and bait shipments, aquaculture, shipments of commercial and institutional aquarium species, and the activities of educational and research organisation. It is thought that marine traffic is the main cause for species entering new areas worldwide because of the hitchhikers they can carry associated either with hull fouling or ballast water (De Poorter, 2009). Shipping vessels can act as biological islands for species that live in harbours and estuaries around the world (Wonham *et al.* 2001), as ships transit or dock in these areas, some species take advantage and hitch a ride. These vessels provide areas for the settlement of species associated with fouling communities, protected nooks and crannies where both sessile and mobile fauna can settle and enclosed spaces that hold water in which a wide range of organisms from plankton to fish can travel (Wonham *et al.* 2001; Godwin, 2003).

Another vector that has been studied in recent years is marine debris. The possibility has been explored that marine non-native species can adhere themselves to floating waste and can be transported to different bioregions. Hilliard (2004) states that several who are examining the marine debris problem have raised the role of marine debris as a transport vector for floating fouling species, but solid field of evidence is still in the preliminary stages. A good example of floating debris are fishing nets that are lost and are carried by currents to different locations, potentially invasive species can adhere to these nets and relocate. Similarly, the same problem arises with fish aggregating devices (FAD) that are left by illegal fishing boats.

Other types of vectors exist that can disperse marine organisms throughout the world and these are those influenced by natural causes, for example, currents, migrating species and natural phenomena such as tsunamis. A year after the devastating earthquake and tsunami that occurred in Japan in 2011, a floating dock appeared on the coast of Oregon in the United States with several invasive species attached to it, some examples are: *Undaria pinnatifida* “wakame” the brown kelp algaean invasive species of high concern, *Hemigraspus sanguineus* the Japanese shore crab and *Asterias amurensis* the northern pacific starfish (Chan, 2012). This shows how it is possible for invasive species to be transported across a large body of water due to currents and winds. The Japanese Ministry of the Environment estimates that 5 million tonnes of debris was washed into the ocean, it is estimated that 30% floated away and dispersed (Chan, 2012). The National Oceanic and Atmospheric administration (NOAA) used a computer model to simulate the movement of the tsunami debris by using a particle displacement model to estimate where the debris could be now as well as where it could end up. NOAA expects more debris could be washed up on the coasts of the United States and Canada in the next several years (NOAA, 2013).

A pathway can be described as a geographic routetaken by one or more vectorsfrom point A to point B. (Hilliard, 2004).The primary pathway identified for marine species introductions has been by maritime traffic to ports around the world and the discharge of ballast water (Godwin, 2003; Ruiz *et al.* 2000). However there are other pathways associated with maritime traffic that can be responsible for introductions such as ballast water sediment and hull fouling (Godwin, 2003). The stronger the pathway, the more likely it is to lead to the establishment of non-native populations (Lockwood *et al.* 2009).

2.5 Marine traffic

Marine organisms have spread from their native regions through human transport and have managed to establish populations in different parts of the world (Cohen & Carlton, 1998). The rate of biological invasions has strongly increased during the last decades, mostly due to the accelerated spread of species by increasing global trade, transport and tourism. This has occurred through the effective violation of natural barriers, such as currents, land masses and temperature gradients that once limited the movement of species (Hilliard, 2004; Seebens *et al.* 2013). The rates of marine introductions and spread are inherently variable but there is little doubt they have been increasing since the 1960s (e.g. Carlton, 1996; Cohen & Carlton, 1995; Ruiz*et al.*1997).The globalisation of maritime traffic plays a key role in the spread of species due to the fact that many of these organisms are moved between regions by cargo ships (Kolar & Lodge, 2002; Hulme, 2009). Although most organisms die in transit, or soon after release, those that survive can cause great effects on human health, economic impacts and can threaten native biodiversity and ecosystem functions (Kolar & Lodge, 2001).

Marine species have been moved around the world since sailing began and movement between regions began. It is thought that species began being transported on wooden hulls as fouling organisms. Following this came "dry ballast" which transported species from beaches and rocky shores. However it is ballast water that is the biggest problem nowadays and it is estimated that 10,000 species are transported around the world in ballast water every day, due to the increasingly larger and faster cargo ships (De Poorter, 2009; Hutchings *et al.* 2002; Bax *et al.* 2003). Historical records and studies on modern replicas indicate that wooden sailing ships were often heavily encrusted with fouling organisms. A wooden sailing vessel in 1750 could have carried up to 120 marine organisms fouling, boring into or nestling on the hull; and a further 30 associated with dry ballast and the anchor chain (Bax *et al.* 2003).Shipping carries more than 80% of the world trade and in the process 12 billion tonnes of ballast water per year. Over the last 30 years, the shipping industry has more than doubled from 2490 million tonnes in 1970 to 5330 million tonnes in 2000 (Bax *et al.* 2003). As the boating industry grows so does the danger of species being transported (Figure 2.3).The globalisation of maritime trade plays a key role in the accelerated spread of species many of which are dispersed by cargo ships (Kolar & Lodge, 2002; Seebens *et al.* 2013). The study conducted by Seebens *et al.* (2013) shows a model of marine bioinvasions where it estimates the likelihood of a new invasion for every port vessels dock in. Three parts are taken into account 1) the probability to be non-native 2) the probability of introduction and 3) the probability of establishment.

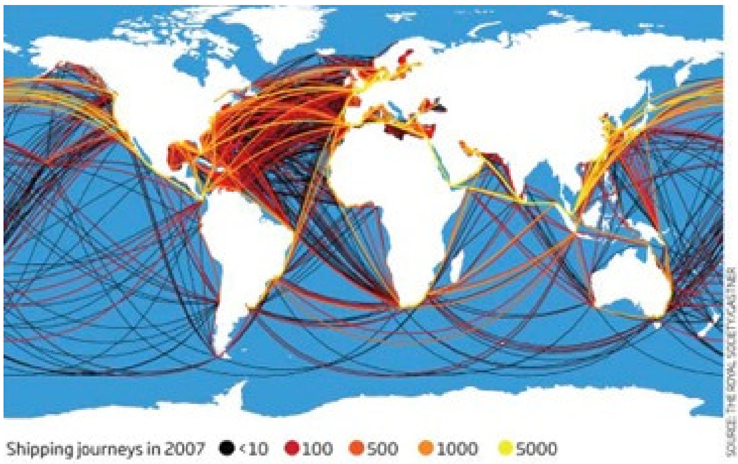


Figure 2.3: Worldwide shipping traffic 2007 (Seebens *et al.* 2013)

Understanding transportation pathways can provide information when predicting where the next invasive species are likely to come. For example, MacIsaac *et al.* (2002) conducted an analysis of transport patterns to and from the North American Great Lakes the results showed that non-native amphipods, zooplankton, mussels, and fishes have been transported primarily along the major shipping routes between the Great Lakes and northern and western Europe

(Lockwood *et al.* 2009). In addition, heavily invaded regions or ports could serve as hubs for the transport of non-native species to nearby smaller ports that would not normally receive such organisms due to the fact that smaller ports cannot accommodate large ships (Figure 2.4) (Lockwood *et al.* 2009).

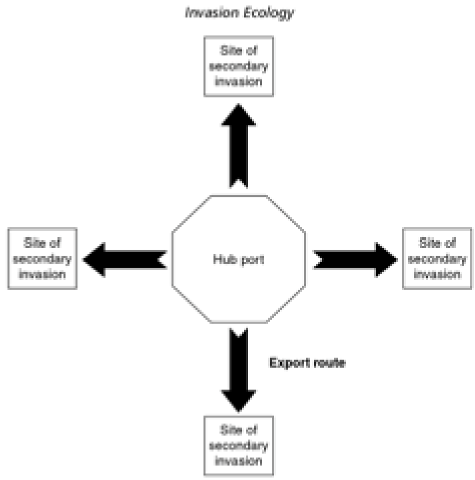


Figure 2.4: Hub and spoke diagram showing how some ports can accumulate non-native species and help disperse (Lockwood *et al.* 2009).

2.5.1 Past and present marine traffic in the Galapagos Islands

The history of the maritime traffic in the GMR is extensive, which makes it more difficult to know with certainty if some species existed naturally or if humans introduced them in the past. Since their accidental discovery in 1535 and through the 17th and 18th centuries, the Galapagos Islands became a haven for pirates. Then in the 19th century, whalers were attracted by the richness of the sea surrounding the Islands. The first introductions of domestic animals and invertebrates occurred during these centuries. Various marine species could also have been introduced at this time. A possible example is *Bugula neritina*, a brown bryozoan that has a worldwide distribution, which is thought to have been transported on wooden hulls (Eldredge & Smith, 2001) and could have arrived in the Galapagos through this mechanism in centuries past. Industrial-fishing boats arrived during the 1940s and 1950s (Cruz *et al.* 2007), and in 1942 during the Second World War, the United States of America constructed a naval base on Baltra Island, which increased the number of vessels in the area (Keith *et al.* 2015).

Due to the constant increase in human activities over the past 40 years, marine traffic has increased which means an increased risk of possible transmission of species from one bioregion to another. In the case of the Galapagos Islands, tourism is the main base of its economy (Piu & Muñoz, 2008), where the majority of tourists explore the islands by boat. While there has not been a substantial increase in the number of vessels operating in the Galapagos Marine Reserve in the last 15 years, there has been a significant increase in the number of passengers and the number of days the vessels operate (Epler, 2007). This increase has generated intensive use by tourist boats in the most visited sites. Maritime traffic in the Galapagos Islands is one of the main access points (Campbell & Hewitt, 2007). There have been some preliminary studies conducted that give an idea of the amount of maritime traffic and the potential problem the GMR is facing. There has been an increase in marine traffic between the four populated islands related to the increase of tourists and residents requiring mobilization between them. The number and frequency of cargo ships and other vessels sailing between mainland Ecuador and the Galapagos Islands have also increased in recent years, as have private yachts that sail in from different parts of the world (Figure 2.5). These private yachts are of high risk to the GMR as these boats stop in various ports before arriving to the GMR and could transport non-native species on their hulls (Cruz *et al.* 2007).

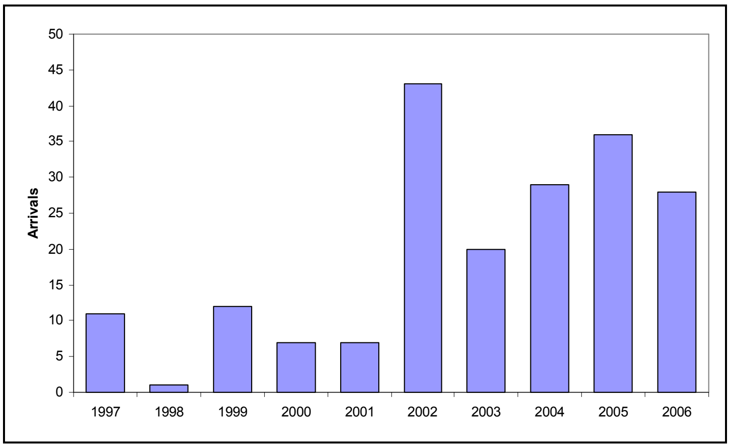


Figure 2.5: Arrivals of annual international tourist boats to the Galapagos Islands (Cruz *et al.* 2007)

2.6 Climate change and climate variability

Non-native species and climate change are two of the most prevalent issues facing biodiversity (Rahel & Olden, 2008). Climate change is altering the environment due to increasing temperature, precipitation, the frequency of extreme climatic events and the atmospheric composition. Temperature, concentrations of carbon dioxide (CO_2) and nutrients are key for species survival; therefore, if changes occur the ecosystems will become stressed allowing for an invasion to occur (Dukes & Mooney, 1999). Climate change is expected to warm the earth's surface and increase air and water temperatures, causing effects on ecosystems and services (Rahel, 2002; Hare & Whitfield, 2003). When a habitat has been changed for example through climate change, non-native species can use the disturbed habitat to establish and spread a lot easier than if the system was stable and could fight the invasion. Climate change is affecting biodiversity due to temperature and/or rainfall patterns changing. It is a fact that the native species struggle to adapt to new conditions, on the other hand, invasive species are excellent in adapting, establishing and spreading (Emerton & Howard, 2008). Aspects that can be altered by climate change (Figure 2.6) and how these changes will affect non-native species are of great importance when looking at invasions of non-native species.

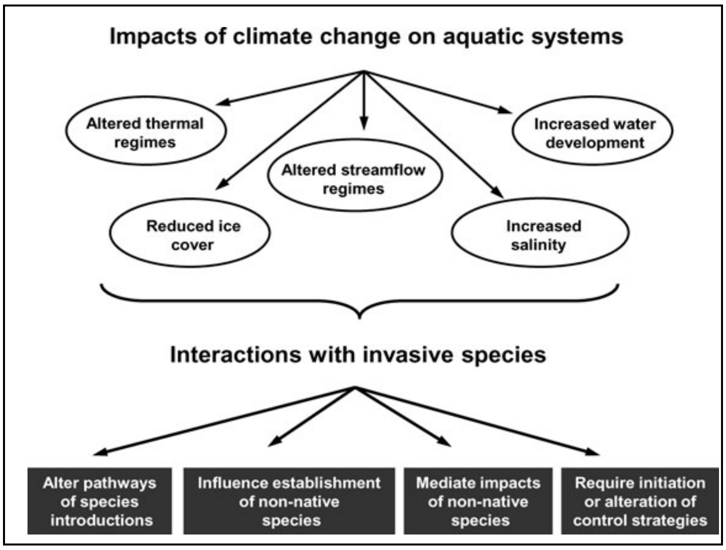


Figure 2.6: Impacts of climate change on invasive species (Poff *et al.* 2002; Rahel & Olden, 2008)

Similarly to Poff *et al.* (2002) and Rahel & Olden (2008), Hellmann*et al.* (2008) state that there are five consequences of climate change for invasive species. 1) altered transport of invasive species, 2) altered climatic constraints on invasive species, 3) altered distributions of existing invasive species, 4) altered impact of existing invasive species and 5) altered effectiveness of management strategies. Recent climate changes are linked to increases and declines in population size and specifically rapid declines are of major concern. Increases in valued species will likely be offset by population increases in groups such as invasive species (McCarthy, 2001).

The changes in climatic conditions that have occurred over recent decades have resulted in altered population dynamics of native species, consequently changing their geographic ranges, the structure and composition of communities and functioning of ecosystems (Gritti *et al.* 2006; Parmesan, 2006; Walther *et al.* 2002; Walther *et al.* 2009). Similarly to native species, climate change might also directly influence the likelihood of non-native species being introduced into a territory and also affect their chances of establishing. In extreme cases, climate-driven invasions could lead to the complete transformation of ecosystems where non-native species dominate reducing the diversity of native species (Mack *et al.* 2000; Walther *et al.* 2009). With further global warming, non-native species originating from warmer regions could build up numerically and spatially larger populations that might spread to wider areas. A climate-mediated invasion process follows the classic invasion process (Figure 2.7) (Walther *et al.* 2009).

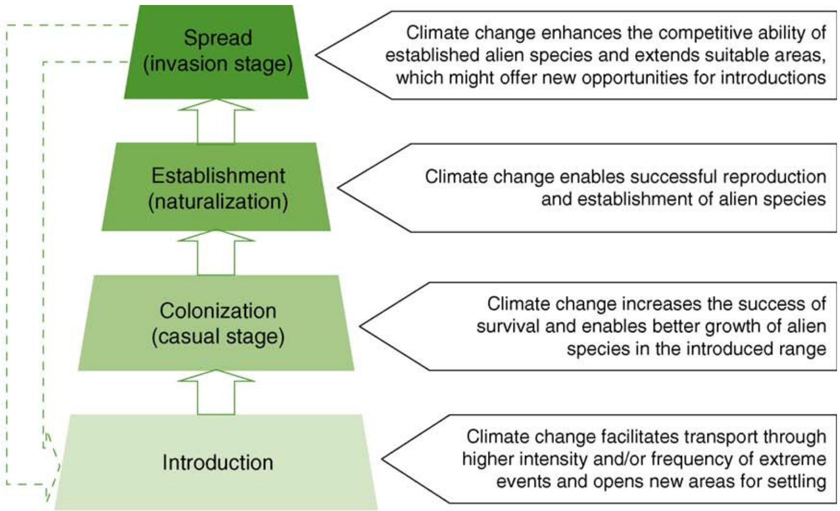


Figure 2.7: Influence of climate change on the invasion process based on Richardson *et al.* (2000) (Walther *et al.* 2009)

2.6.1 Currents and ENSO events in the Galapagos Islands

El Niño Southern Oscillation is a naturally occurring fluctuation that originates in the tropical Pacific region that affects ecosystems. These events are some of the most prominent sources of inter-annual variations in weather and climate around the world (Trenberth & Caron, 2000; McPhaden, 1999). It occurs in irregular cycles within periods of two to ten years and is defined by 'El Niño' a warm phase with weak winds and 'La Niña' a cold phase with strong winds that often have devastating effects on the flora and fauna of the area (Philander, 1985; Chavez *et al.* 1999). These swings in temperature are accompanied by variability in the strength of the equatorial easterly trade winds and shifts in the position of atmospheric convection lead to variations in rainfall and weather patterns in many parts of the world (Collins *et al*. 2010). Under the influence of global warming, the mean climate of the Pacific region could undergo significant changes for example: The trade winds are expected to weaken, surface ocean temperatures are expected to increase near the equator, the equatorial thermocline is expected to shoal, and the temperature gradients across the thermocline are expected to become steeper (Collins *et al*. 2010). There is a lot to learn about the impact of ENSO events on climatically controlled patterns of plant and animal distribution in the tropics. (Philander, 1985).

Climate change will interact with other existing stressors to affect the distribution, spread, abundance, and impact of non-native species (Hellman *et al.* 2008). Researchers think it is possible that with climate change the emergence of new invasive species will increase possibly shadowing existing invasive species. This will not mean that the impact of invasive species will decrease it means new invasive species can appear (Hellman *et al.* 2008).

The Galapagos marine ecosystem is home to several distinct biological communities due to the confluence of currents and its connectivity to the ETP. The archipelagos oceanic framework is unique worldwide and is considered largely responsible for the colonization of the islands that led to the evolution and the presence of the diverse species that exist there today. The geological, oceanographic and climatological aspects of Galapagos need to be taken into account to understand the biodiversity of the islands (Banks, 2002). A high incidence of endemic species is maintained, which are regularly subjected to extreme climatic variability through ENSO events.

The archipelago is influenced by a number of major surface and submarine current systems and are characterized by a diverse wildlife compared to other islands, with representatives corresponding to the Indo-Pacific, Panama, and Peru biogeographic regions, the archipelago also has a high percentage of endemic species of macroalgae, sea birds and fish (Danulat & Edgar, 2002). In the GMR, there are three regimes of prevailing ocean currents that show a marked seasonality in their intensity and direction (Chavez & Brusca, 1991). The South-Equatorial Current (SEC) conformed by the confluence of the Panama Current from the Northeast and the Peru or Humboldt Current from the southeast and the Equatorial Undercurrent (EUC) or Cromwell Current from the west (Muromtsev, 1963; Banks, 2002), which brings cold upwelling waters mainly to the western part of the Archipelago (Hickman, 2009)

The Galapagos Islands sustain a high incidence of endemic species, which are nonetheless regularly subjected to extreme climate variability through ENSO events. During 1982-1983 and 1997-1998 two strong El Niño events where marked with widespread damages caused to the marine ecosystem of the Galapagos Islands, largely due to food shortage (Danulat & Edgar, 2002). Marine Iguanas rely on green algae when temperatures increase due to ENSO events the green algae dies off leaving marine iguanas with limited food sources.

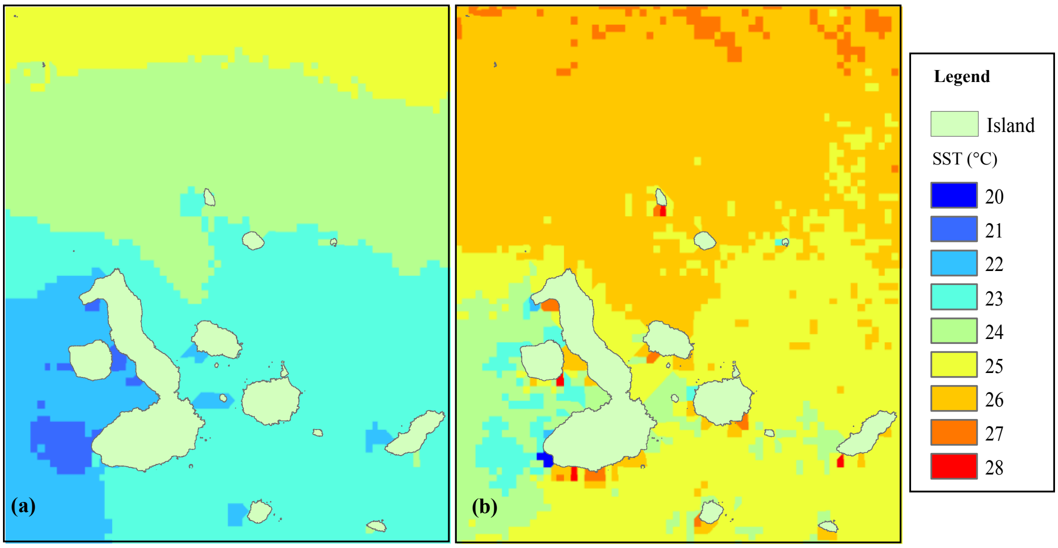


Figure 2.8: Average SST data around the Galapagos archipelago (a) non El Niño SST and (b) SST during El Niño events (Dawson *et al.* 2009)

During normal conditions, the west of the archipelago is strongly influenced by the cold upwelling of the EUC while the warmer tropical water from Panama and the cold subtropical waters from the Peru Current set differentiation which varies in intensity throughout the year (Figure 2.8a). During ENSO events, prolonged increases in sea temperature (Figure 2.8b) are induced as the warm surface waters of the western Pacific band migrate to the coast of South America (Banks, 2002).

During such events when extreme conditions occur, the geographic range of some warm water species can expand moving them to different regions. In the GMR, the Green Sea urchin populations *Lytechinus semituberculatus* decreased during the last strong event, in contrast, the White Sea urchin *Tripneustes depressus* showed high rates of recruitment after the El Niño event (Brandt & Guarderas, 2002; Danulat & Edgar, 2002). On the other hand, microalgae are particularly affected by rising sea temperatures because unlike fish and invertebrates, algae are not able to migrate to colder and deeper waters where they can stay until conditions return to normal (Garske, 2002; Danulat & Edgar, 2002). The loss of green and red algae during warm events can also lead to an increase in iguana mortality and creating invasion niches. These are just some of the examples that indicate how a strong ENSO event can influence populations, changing them and giving invasive species a great window of opportunity to take over an affected area.

2.7 Ocean circulation and connectivity

Ocean circulation can be described as a combination of currents driven directly by winds, currents driven by fluxes of heat and freshwater across the sea surface and tides driven by the gravitational pull of the Moon and Sun (Figure 2.9) (Rahmstorf, 2002). An important way in which wind-driven currents are thought to lead to climatic changes is through their effect on upwelling near coasts and the Equator changing sea surface temperatures that in turn plays a role in ENSO events (Rahmstorf, 2002).

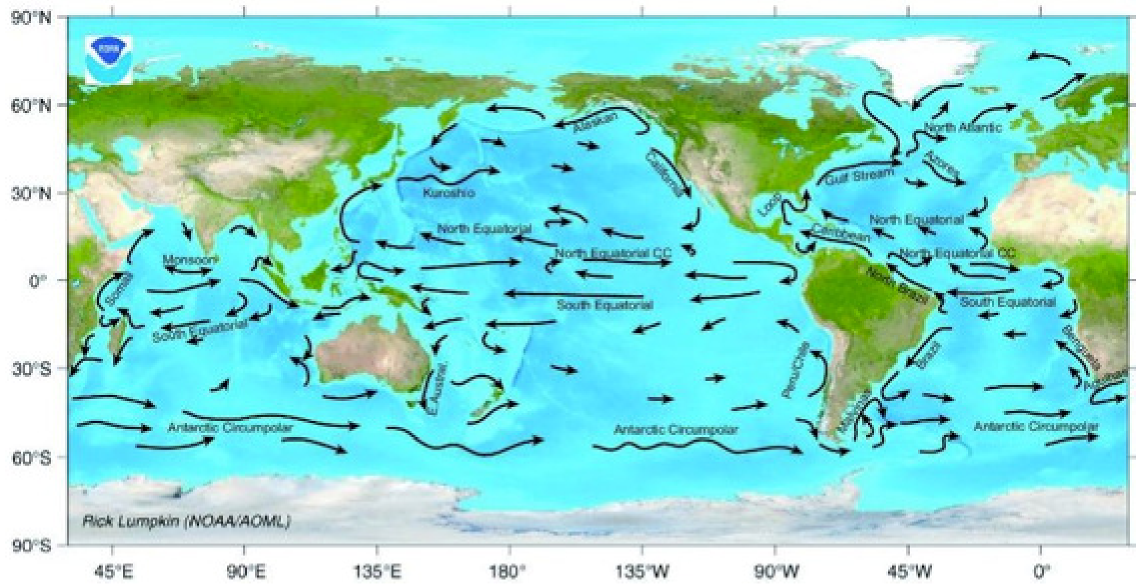


Figure 2.9: Map illustrating the major surface current circulations worldwide©Rick Lumpkin-NOAA.

The circulation of the ocean is usually divided into two parts, a wind-driven circulation that dominates in the upper few hundred meters, and a density-driven circulation that dominates below. The latter is called the 'thermohaline' circulation because of the role of heating, cooling, freshening, and salinification in producing regional density differences within the ocean (Toggweiler, 2001).

Modelling oceanic circulation has become more popular in recent years and reasons for this include the widespread realization that model solutions can skilfully mimic observed oceanic features of importance like the compelling problems of anthropogenic changes in climate and the environment (McWilliams, 1996). In dealing with the ocean it is extremely helpful to appeal to the simulation capability of models to improve understanding of basic processes and their interconnectedness, as well as to help interpret sparse observations (Semtner, 1995).

Models can be used to simulate possible invasions by non-native species to a certain region although predicting the distribution of non-native species that exhibit low habitat occupancy and patchy distributions in time and space can be difficult. Simple predictive habitat mapping and particle displacement models can be used to target marine pest incursions (Inglis *et al.* 2006). Predictive habitat mapping describes the range of techniques that are used to derive spatially explicit distribution models of habitat structure and quality from underlying physical gradients, the basic approach utilizes geographic information systems (GIS) to integrate digital spatial data on physical characteristics of the environment with species responses to combinations of these physical variables (Franklin, 1995; Inglis *et al.* 2006). The Lagrangian numerical modeling is an increasingly popular approach, to better understand the influence of transport vectors on marine ecosystems. A particle-tracking framework can be used to examine the variability of major currents, the connectivity, the spread of non-native species and marine diseases (Paris *et al.* 2013). For most marine organisms with sessile, benthic or sedentary adult phases, movement is often limited to their larval phase, this movement is defined as ‘dispersal’. However, these early life history stages are never entirely passive and represent a unique opportunity for individuals to “migrate” between geographically separated populations using the currents (Paris *et al.* 2013; Pineda *et al.* 2007). During the last decade, numerical models to study larvae have become a powerful tool to investigate the link between the mixing of sedentary populations and the spatial history of successful migrants. These models typically use a Lagrangian particle-tracking framework to deal with explicit individuals, and use information on currents and environmental conditions from ocean circulation models to track the movement of a large number of individuals through space and time (Paris *et al.* 2013).

2.8 Marine invasive species worldwide

Marine non-native species can cause many environmental impacts such as loss of native biodiversity, changes to ecosystem functions, changes to nutrient cycles, decreased water quality, sedimentation and displacement of native species (De Poorter, 2009; Molnar *et al.* 2008; Bax *et al*. 2003). Once an invasion occurs the economic impacts can be incredibly high. The clean-up and control operations along with the treatment and quarantine measure can be astronomical. Fisheries can be greatly affected in cases when fish or shellfish stocks collapse, or when mariculture is affected by alien species. Another serious impact is the damage that marine invasive species can do to local infrastructures through fouling (De Poorter, 2009; Bax *et al.* 2003). In terms of human health and wellbeing non-native species can also cause an impact though parasites and diseases, which can be lethal in some cases. They can also disrupt tourism or recreational opportunities when algal slicks occur or with the smothering of beaches, which can affect the local economy (Bax *et al.* 2003).

The issue of marine non-native species has grown in recent years and how to control and eradicate these pests is quite complicated. Governments around the world have established programs and protocols for the prevention, early detection and management of marine non-native species. Examples include the Marine Biosecurity Programme of New Zealand, the National System for Prevention and Management of Marine Pest Incursions of Australia, Aquatic Nuisance Species Task Force (ANSTF) in the United States.

The following are some examples of the invasions that have occurred around the world; these examples show introductions that have been controlled through control and eradication programs and others examples of introductions that have not yet been able to eradicate.

Mytilopsis sp. the black-striped muscle is known to have invaded port communities throughout the Indo-pacific and in 1999, it was introduced into the Port of Darwin, Australia (Hewitt, 2002; Bax *et al.* 2002). The eradication operation for this species directly involved 280 people and cost over A$ 2.2 million, not including staff costs (Bax *et al.* 2001).

Caulerpa taxifolia the "Killer algae" has caused large amounts of damage in different parts of the world. In the Mediterranean it has spread steadily since its introduction in 1984 and has spread to six countries with 103 independent areas of colonization, involving 131 km^2 of concerned area along a 191km of coastline (Meinesz *et al.* 2001). It is thought it will spread over most of the Mediterranean (Bax *et al.* 2003). In 2000 the Mediterranean strain of *Caulerpa taxifolia* was identified in California (Williams & Grosholz, 2002). It has caused devastating ecological and economic problems in California, up to 2003 it cost the United States Government $3.9 million in eradication and control measures (Woodfield & Merkel, 2004).

Dreissena polymorpha the zebra mussel was first found in Canada in 1986 then later in 1988 in the Great Lakes in the United States. This species is thought to have been transported in ballast water from Europe and since its arrival has caused problems by displacing many native muscles, it also colonises docks, locks, ship hulls, water intake pipes and has caused great damage to power plants and water treatment facilities in the area(Carlton, 2008; Ruiz *et al.* 1997; Lovell *et al.* 2006). *Dreissena polymorpha* in the Great Lakes has changed the community structure and function. For the year 2000, it was estimated that it would cost the United States government between $1.8 and $3.4 billion in control measures (Ruiz *et al.* 1997).

Pterois volitans the lionfish is thought to have been introduced to the Atlantic Ocean through aquarium trade; it is not certain when or where it was first introduced, but there is evidence that there were accidental introductions in Florida in 1992 due to a hurricane (Hare & Whitfield, 2003). The lionfish is now established along the Atlantic coast of the United States and the Caribbean. This species feeds on a variety of small fish, shrimp and crabs this can cause serious damage to native ecosystems through predatory interactions. It is believed that the eradication of this species is almost impossible but it can be controlled in some places (Hare & Whitfield, 2003).

Undaria pinnatifida the Japanese kelp also known as "Wakame" is native to the cold and warm temperate Northwest Pacific including China, Japan, Korea and Russia (Hewitt *et al.* 2005). Since the 1970s this species has spread extensively and established populations in Argentina, Australia, Belgium, England, France, Italy, the Netherlands, New Zealand, Spain and most recently in California in the United States (Hewitt *et al.* 2005; Silva *et al.* 2002). This invasive species can cause changes in ecosystem structure (Thornber *et al.* 2004).

The above examples describe how difficult and expensive it is to control or try to eradicate a species once it has arrived. It is estimated that marine non-native species cost the USA up to $120 billion per year (Pimentel *et al.* 2005). In some cases like *Undaria pinnatifida* in New Zealand, an extreme amount of effort and resources were put into trying to control and eradicate this species without the desired outcomes. Once a non-native species arrives to a new region it is very difficult and highly unlikely to be able to remove the species (Minchin *et al.* 2009).

2.9 Danger of invasion

The possible invasion of marine species to the GMR given these possible climate changes and the connectivity that exists in this bioregion is a reality that should not be ignored (Keith *et al.* 2015). The Galapagos Islands has great connectivity with the rest of the ETP and understanding the different human influences that the GMR receives are a priority in order to protect the biodiversity of the archipelago. Oceanic currents heavily influence trans-oceanic dispersal and these currents make it possible for species to be dispersed between widely separated areas, especially species capable of long distance larval transport (Hickman, 2009). The islands are no longer considered an isolated place and the dynamic convergence of different oceanic regimes provides incredible connectivity, which is partly responsible for its unique biodiversity (Hickman, 2009). The main risks in the loss of ecosystem processes and biodiversity come down to factors such as climate, fisheries, marine traffic density, pollution and extreme natural events such as a tsunami (Banks, 2002). To better predict the effects of a possible invasion and the way these variables might influence need to be investigated in the event a species invades and establishes in the GMR. The geographic opening of a region can be defined by the profound ecological and/or social transformations consequent to increased and uncontrolled connection of this region with the rest of the world (Grenier, 2010). The human history of Galapagos reveals a gradual geographic opening of this region to the rest of the world and coincides with the formation of the Modern World system. A world system connects various regions in different continents or oceans via transportation networks that permit a regular flow of materials (raw materials, products, etc.), people, money, organisms, and ideas (Grenier, 2010). The growth of tourism and migration associated with the islands in the last 20 years has led to a dramatic increase in the number of exotic species introduced (CDF & WWF, 2002). The number of vessels arriving in the Galapagos from different parts of the world due to the connectivity has increased in recent years, increasing the possibility of an invasion. As tourism and commerce grows in the islands the higher the risk of an invasion by marine invasive species. An efficient policy to support conservation and social sustainability must act on the connections between Galapagos, continental Ecuador, and the rest of the world, to reduce the flows that enter and leave the archipelago (Grenier, 2010).The introductions of species and their subsequent proliferation in the archipelago have been identified for well over a decade as the principal threat to the conservation of Galapagos (CDF & WWF, 2002).

2.10 Marine non-native species established in the GMR

The literature search produced seven non-native species (Table 2.2) reported in the GMR. The first record found was for *Caulerpa racemosa*and this species was registered in Galapagos by Farlow in 1899 on the Island of Isabela and was registered again by Allan Hancock during the Pacific Expeditions (Eldredge &

Smith, 2001; Farlow, 1902; Molnar *et al.* 2008; Ruiz & Ziemmeck, 2014; Taylor, 1945). Dawson first registered *Asparagopsis taxiformis* in the Galapagos in 1963, (Chualáin *et al.* 2004; Dawson, 1963; Ruiz & Ziemmeck, 2014; Taylor, 1945). According to (Hickman, 1997) the blue crab *Cardisoma crassum*was an introduction to the Galapagos Islands, although the evidence is uncertain. It was thought it was originally introduced when some live crabs escaped after being taken to a hotel in the town of Puerto Ayora on the Island of Santa Cruz. However in a publication on land crabs of Costa Rica, Bright (1966) reports the presence of the blue crab in the Galapagos Islands. On the other hand, Garth (1991) cites this species as absent and with undetermined invasiveness. *Bugula neritina* and *Pennaria disticha*werefirst registered during the Allan Hancock Pacific Expeditions, (Danulat & Edgar, 2002; Eldredge & Smith, 2001; Hickman, 2008; Ryland *et al.* 2001; Taylor, 1945; Molnar *et al.* 2008; Vieira *et al.* 2012). Hickman first reported*Acanthaster planci* in the Galapagos, it is only found at Darwin Island in the north of the Archipelago (Cohen-Rengifo *et al.* 2009; Hickman, 1998). A small colony of *Schizoporella unicornis*was reported by Osborn (Taylor, 1945) on the Island of Santiago between 1932 and 1949 by the Allan Hancock Pacific Expeditions. In his report, Osborn cites that this species had not been found previously on the Pacific coast and goes on to suggest that it could have been a recent introduction (Banta & Redden, 1990; Taylor, 1945).

Table 2.2: List of non-native species reported in the GMR found in the literature search

Phylum	Family	Scientific name	Common name
Chlorophyta	Caulerpaceae	*Caulerpa racemosa*	Grape algae
Rhodophyta	Bonnemaisoniaceae	*Asparagopsis taxiformis*	Red sea plume
Arthropoda	Gecarcinidae	*Cardisoma crassum*	Blue crab
Bryozoa	Bugulidae	*Bugula neritina*	Brown bryozoan
Cnidaria	Pennariidae	*Pennaria disticha*	Christmas tree hydroid
Echinodermata	Acanthasteridae	*Acanthaster planci*	Crown of thorns
Bryozoa	Schizoporellidae	*Schizoporella unicornis*	Single horn bryozoan

2.11 Potential non-native species for the GMR

Data collected on marine non-native species worldwide highlighted 18 high-risk species with the potential to arrive to the GMR through one of the various vectors mentioned previously. Several methods exist for obtaining high-risk species lists. In section 4.6 of this thesis, a species-based exposure analysis was used to obtain a high-risk species list using marine traffic data and relating it to world eco-regions and whether the species could survive/thrive and invade the new region.Table 2.3 was derived by going throughthe Global Invasive Species Database (ISSG, 2015) and NIMES. The species worldwide distribution was analysed as well as the habitat suitability for these species along with the potential threat of these species being transported to the GMR. These species are also ranked as very invasive worldwide and have caused harm to several marine habitats worldwide.

The list in this section (Table 2.3) is an example of the various non-native species that could arrive to the GMR. However, this list will keep growing as more research unfolds and more high-risk species are found along with new vectors that can transport them. These species are considered to be of high-risk and problematic due to the reported impacts they have caused in other parts of the world. This section follows on to give a short description of each high-risk species distribution, habitat, possible vectors and the impacts each species could cause.

Table 2.3: List of potential non-native species for the GMR

Phylum	Family	Scientific name	Common name
Echinoderm	Asteriidae	*Asterias amurensis*	Northern Pacific Seastar
Anthropoda	Chthmalidae	*Chthamalus proteus*	Caribbean barnacle
Mollusca	Dreissenidae	*Mytilopsis sallei*	Blacked-striped mussel
Ochrophyta	Alariaceae	*Undaria pinnatifida*	Japanese Kelp “wakame”
Cnidaria	Clavulariidae	*Carijoa riisei*	Snowflake coral
Chlorophyta	Caulerpaceae	*Caulerpa cylindracea*	Grape algae
Chlorophyta	Codiaceae	*Codium fragile*	Sponge weed
Rhodophyta	Bonnemaisoniaceae	*Asparagopsis armata*	Harpoon weed
Rhodophyta	Gracilariaceae	*Gracilaria salicornia*	Red alga
Rhodophyta	Cystocloniaceae	*Hypnea musciformis*	Hook weed
Rhodophyta	Rhodomelaceae	*Acanthophora spicifera*	Spiny seaweed
Mollusca	Chamidae	*Chama macerophylla*	Leafy jewelbox
Cnidaria	Diadumenidae	*Diadumene lineata*	Orange-stripped green

			anemone
Chordata	Didemnidae	*Didemnum candidum*	White didemnid
Porifera	Chalinidae	*Haliclona caerulea*	Blue Caribbean sponge
Arthropoda	Portunidae	*Carcinus maenas*	European green crab
Chordata	Lutjanidae	*Lutjanus kasmira*	Blue stripped snapper
Chordata	Scorpaenidae	*Pterois volitans*	Lionfish

***Asterias amurensis* Lutken, 1871:** This species inhabits of estuarine and marine environments with water temperatures ranging between 7°C and 10°C, although it has adapted to warmer waters in Australia of up to 22°C. It prefers protected shallow coastal waters, estuaries and protected mud, sand or rocky intertidal zones. It does not occur in reefs or areas exposed to wave action (Cohen *et al.* 2000; Hewitt *et al.* 2004). This species is able to tolerate wide ranges of temperature (0°C to 25°C) and salinity (18.7 to 41) and has been recorded at a depth 200m (NIMPIS, 2013). It is native to Japan, North of China, Korea, Russia and the northern Pacific. It has been introduced in southwest Australia including Victoria and Tasmania (Cohen *et al.* 2000; Byern *et al.* 1997).The vectors for this species are believed to be shipping and natural dispersion (NIMPIS, 2013). Currents and ballast water can disperse the larval phase of this species. Other vectors include boat hulls (biofouling), fisheries (transferring material and equipment, cages, lines and aquaculture equipment). This species has a high potential as a colonizer; it is a voracious predator in its native range of Japan it is a major pest for the Japanese shellfish farming industry. In its introduced distribution range, for example, Australia the seastar feeds on a wide range of native animals this can have a major effect on the recruitment of native shellfish populations that are important in the marine food chain. Recent studies indicate that the sea star is now affecting commercial shellfish production in southeast Tasmania (Cohen *et al.* 2000; Goggin, 1998; Hewitt & Campbell, 2007; Mah, 2015b; NIMPIS, 2013).

***Chthamalus proteus* Dando & Southward, 1980:** This species is intertidal and inhabits protected areas of ports and harbours as well as on port structures and boat hulls. It is native to the Caribbean, from the Gulf of Mexico to Trinidad and north east of Brazil. It has been introduced in the Western Atlantic, Hawaii, Midway Atoll and Guam. The vector for dispersion for this species is through biofouling on boat hulls. The ecological impacts of this barnacle are unknown at the time (Hickman, 1997; Southward *et al.* 1998; Hewitt & Campbell, 2007; WoRMS, 2015a).

Mytilopsis sallei **(Récluz, 1849):**has a large tolerance range of temperature, salinity and dissolved oxygen. It also has a rapid growth rate, high fecundity and early maturation. In its native habitat, *M. sallei* colonies can grow in shallow coastal lagoons. In its introduced habitat it is found in the intertidal zone and shallow water with a temperature range of (10°C to 35°C) and salinity of (0 to 27). It prefers disturbed habitats commonly settling on man-made structures. This species has not been found deeper than a few meters of water. It prefers to settle on vertical surfaces and objects, but it is found in all substrates (Bax *et al.* 2002; Cohen *et al.* 2000; Morton, 1981; Udhayakumar & Karande, 1989). *M. sallei* is native to the West Indies, along the Caribbean coast of Central and South America, from Yucatan to Venezuela, and in the southern part of the peninsula of Florida, USA (Bax *et al.* 2002). It has been introduced to Hong Kong, Taiwan, Japan, Hong Kong, Taiwan, Japan, Fiji, India, Singapore and Australia (Bax *et al.* 2002; Cohen *et al.* 2000; Morton, 1981; Udhayakumar & Karande, 1989). The main mechanism for introduction is on boat hulls, during the 1990s, there were several introductions to Darwin Harbour, Australia through ship biofouling (Hutchings *et al.* 2002). It is possible that this species could have been transported by ballast water, however, this not thought to be the case due to their short larval stage, there is the possibility of introduction throughaquaculture with the movement of equipment, (CRIMP, 2001). *Mytilopsis sallei* is an extremely prolific and fecund species, similar ecologically to its relative, the zebra mussel *Dreissena polymorpha.* It has been responsible for massive coverage of piers, marinas, water pumping stations, ship ballast systems, cooling systems and marine farms. In suitable habitats they form dense aggregations that exclude most other species, leading to a substantial reduction in biodiversity (Cohen, 2011; NIMPIS, 2009; Rosenberg & Huber, 2015).

Undaria pinnatifida **(Harvey) Suringar, 1873:** is an opportunistic alga, able to colonize rapidly new or altered substrates and floating structures. It can form dense beds, creating a dense canopy on a wide range of surfaces and varying exposures, from the low tide level up to 15m in clear water. It resides in areas of cold water below 12°C and grows in a wide range of habitats, from marine protected areas to exposed coasts, and extends vertically from the low intertidal to 18m, although it is most common between 1 and 3 meters. *U. pinnatifida* tolerates a wide range of radiation from direct sunlight to low light levels but seems unable to invade areas with freshwater inputs. It can grow on any hard surface including artificial substrates such as ropes, piers, buoys, boat hulls, bottles, and plastic pontoons. It grows on rocky reefs, muddy rocks and soft sediment habitats attached to hard surfaces such as shells (NIMPIS, 2009). It is native to Japan, China and Korea; it was accidentally introduced to Australia, New Zealand, Tasmania France and Italy. *U. pinnatifida* was introduced intentionally in the North Atlantic for commercial exploitation. However, natural communities were then registered in France, UK, Spain, Argentina and USA. (Silva *et al.* 2002) The main mode of transport for this species is on boat hulls followed by ballast water, aquaculture and natural dispersion by currents. The impacts of this species are not well understood and appear to vary depending on the location. It can change the structure of ecosystems, especially in areas where native algae are absent. *U. pinnatifida* can cause problems for marine farms, increasing cleaning costs it can affect the efficiency of vessels by to adhering to the hull (Guiry, 2015d; Hayes & Sliwa, 2003; Hewitt & Campbell, 2007; NIMPIS, 2009).

Carijoa riisei (Duchassaing & Michelotti, 1860)**:** This species is never in direct sunlight it prefers nooks and crannies in protected areas of shallow or deeper reefs, it also inhabits port areas or structures dimly lit (Eldredge & Smith, 2001; Grigg, 2003; Kahng & Grigg, 2005). It is native in the West Atlantic from Florida to Brazil and Indo-Pacific and has been introduced in Hawaii, Malpelo and Ecuador (Concepción*et al*. 2010; Grigg, 2003; Kahng & Grigg, 2005; Sanchez *et al.* 2011). It is most likely introduced as fouling on the hulls of boats (Kahng & Grigg, 2005). The ecological impact is not well studied, but it is thought it competes for space with other invertebrates and smothers black corals (Eldredge & Smith, 2001; Kahng & Grigg, 2005; Sanchez *et al.* 2011; van Ofwegen, 2015).

Caulerpa cylindracea Sonder, 1845: can develop over a wide range of depths (up to 70 meters) and is able to colonize all types substrates; sub littoral rock and other hard substrata, sub littoral sediments, soft and hard bottoms, polluted and unpolluted, intertidal (Forrsk, 2012; Galil, 2006). It is native to southwest Australia in areas with temperatures between 14°Cto 22.5°Cand salinity between 35.27 - 37.00PSU (Verlaque *et al.* 2004). Since late 2002, at least, 11 Mediterranean countries (Albania, Croatia, Cyprus, France, Greece, Italy, Libya, Malta, Spain, Tunisia and Turkey) and all major islands (Baleares, Corsica, Crete, Cyprus, Sardinia and Sicily) have been affected (Verlaque *et al.* 2004). The dispersal vectors for this species are mainly through vegetative propagation by random fragmentation, and by specialized propagules formed by detached ramuli. The propagules/fragments may be dispersed by currents or by anthropogenic means (vessels, nets, aquaculture products) (Forrsk, 2012; Galil, 2006). This species has a high invasive potential, with a rapid rate of expansion, it is known to manage total coverage in certain areas within six months of introduction (Galil, 2006; Verlaque *et al.* 2004). It can overgrow other macroalgae and decrease numbers, percentage cover and diversity of the macroalgal community. It can form a dense cover preventing the diffusion of oxygen to the sediment becoming a toxic environment for many species (Galil, 2006; Guiry, 2015e; Verlaque *et al.* 2004).

***Codium fragile* (Suringar) Hariot, 1889:** This species likes estuaries, marine habitats and can also grow and survive in tide pools. It tolerates wide variations in salinity and temperature, colonizing a variety of environments. Appears especially in protected habitats such as harbours and bays, making it easy to transport by human activities. It is native to the Asia-Pacific region and has been introduced to Africa, Australasia, Europe, North and South America (Atlantic and Pacific in both cases). Introduction vectors for this species are Boat hulls, Aquaculture and natural dispersal. *C. fragile* competes for nutrients, decreases biodiversity, causes problems by fouling on aquaculture and prevents re-establishment of native algae (IUCN, 2013; Guiry & Guiry, 2012; Guiry, 2015f; Molnar *et al.* 2008; Ruiz & Ziemmeck, 2014).

***Asparagopsis armata* Harvey, 1855:** is found in temperate waters and conducts vegetative reproduction. It is found in intertidal and subtidal sandy pools or on rock. It is native to Australia and New Zealand and is apparently endemic to the Southern Hemisphere (South and West of Australia, New Zealand and the Chatham Islands, and perhaps Chile (Chualáin *et al.* 2004). First recorded introduction was in 1923 in Algeria it was then recorded in 1949 in the Bristol Channel, UK (Molnar *et al.* 2008). It has since been introduced to the North and East Atlantic, Mediterranean Sea, Southern California and Juan Fernandez Island. There is a record of *A. armata* in the North American Pacific coast, where its distribution is localized in an area of San Diego, possibly indicating a recent introduction (Chualáin *et al.* 2004). This species can be transported through ballast water, boat hulls, natural dispersion and aquaculture. It has been known to dominate algal assemblages in some locations (Chualáin *et al.* 2004; Guiry & Guiry, 2012; Guiry, 2015g; Molnar *et al.* 2008; Ruiz & Ziemmeck, 2014; U.S. Department of the Interior, 2012).

***Gracilaria salicornia*(C.Agardh) E.Y.Dawson, 1954:** particular bushed shaped morphology allows it to adapt to a wide range of light environments while monopolizing nutrients located under the sediment. It is highly resilient to environmental changes in temperature and salinity. It is native to the Indo-Pacific and Philippines and has been introduced to Hawaii. It is thought it got transported through aquaculture, natural dispersion and ballast water. It can damage native corals grow on native benthic organisms such as algae and invertebrates. It can cause biodiversity loss and changes in community structure (IUCN, 2013; Molnar *et al.* 2008; Guiry & Guiry, 2012; Guiry, 2015h).

***Hypnea musciformis* (Wulfen) J.V.Lamouroux, 1813:** are typically attached to corals, rocks or shells in protected reef platforms, they can sometimes be found growing epiphytically on brown algae of the genus Sargassum. This species is native to Florida and was introduced to the Northeast Atlantic, Canary Islands, Mediterranean Sea, Gulf of Mexico, Caribbean, Gulf of Guinea, Red Sea, Indo-Pacific, Hawaii and South Africa. It can be transported through Aquaculture, boat hulls and could get drifted along with the brown algae Sargassum. In certain seasons, it can form dense beds and compete with native sessile (IUCN, 2013; Molnar *et al.* 2008; Guiry & Guiry, 2012; Guiry, 2015i; Ruiz & Ziemmeck, 2014).

***Acanthophora spicifera* (M.Vahl) Børgesen, 1910:** It is found in shallow waters, marshes, shallow reefs and rocky intertidal zones. Often attached to hard substrate (rock, dead coral, etc.) but can be found as epiphyte algae or on other stable floating populations. It can be found at 22m, but is more common in areas between 1-8m. Does not tolerate much air exposure, it can increase its survival in areas where there are different types of algae that are more tolerant to air exposure and are capable of retaining water. This algae is found in tropical and sub-tropical zones, it was introduced to Hawaii and is among the most invasive algae in that area, where competes with native algae species. Local dispersal or vegetative fragmentation is thought to be the transport mechanism for this species (IUCN, 2013; Guiry & Guiry, 2012; Guiry, 2015j).

***Chama macerophylla* Gmelin, 1791:** are always attached to substrate, it is native to the Caribbean and has been introduced to Hawaii this species attaches to boat hulls and becomes a stubborn fouling species, the ecological impact has not been studied, but it is presumed minimal (Allan Hancock Pacific Expeditions, 1948; Coles *et al.* 1999; Hawaii Biological Survey, 2002; Huber, 2015).

***Diadumene lineata* (Verrill, 1869):** is found on solid substrates, intertidal areas, protected shallow waters and ports. Often associated with mussels and oysters. Can also be found in brackish water. Native in the Western Pacific, Japan, China, and Hong Kong and it has been introduced to Indonesia, New Zealand, Hawaii, East Coast of North America and North Atlantic. Vectors for this species are boat hulls or equipment associated with the oyster trade. The ecological impact has not been studied. Seems to be a very tolerant species to environmental variations like salinity and temperature which favours its potential invasiveness (Fautin, 2015; Hawaii Biological Survey, 2002)

***Didemnum candidum* Savigny, 1816:** is found in shallow water, piers or ports, but also found in reef areas. They grow on all types of substrates, including living organisms like animals or algae. It is unclear where this species comes from possibly Indo-Pacific. It has a wide distribution in warm waters. It is introduced throughout the main Islands, and possibly the northwest of the Hawaiian Islands. The introduction of this species occurs through hull fouling. Its ecological impact is unstudied in Hawaii; observations suggest some competition for space with other shallow-water species in harbours (Bungartz *et al.* 2009; Hawaii Biological Survey, 2002; Moreira da Rocha & Sanamyan, 2015a).

***Haliclona* (Soestella) *caerulea* (Hechtel, 1965):** In Hawaii, where it is considered introduced, its distribution is restricted to shallow waters and disturbed areas by human action. It can also be found associated with the roots of red mangrove *Rhizophora mangle*. Its native distribution is the Caribbean Sea or the Eastern Pacific (Panama). It is presently distributed in the Caribbean, East Pacific, main Hawaiian Islands and Guam. It is an accidental introduction, mainly associated with the hulls of boats its ecological impact has not been studied, but it is thought this species probably competes for space with native species (Hawaii Biological Survey, 2002; van Soest, 2015).

***Carcinus maenas* (Linnaeus, 1758):** Inhabits intertidal and shallow waters between 0 and 60m, it is rarely found below 200m. Common in rocky areas and where algae and sea grass is present; it can also be found in areas of high and low salinity (Cohen, 2011). This species can tolerate salinities from 4-54 for short periods of time and temperatures from near freezing up to 33°C (Pourtalés, 1875). This species is native to Europe and North Africa European Atlantic coasts, Northern Britain to Iceland, North Sea and Norway it is also distributed in southern Spain, Portugal, Morocco and northern Mauritania. (Cohen, 2011; IUCN, 2013). Introduced from North Africa to Australia, South America and Southern Africa (IUCN, 2013). *C. maenas* is a voracious species with a very varied diet. It has caused the decline of other native populations of crabs and bivalves in areas where it has become introduced. It has a high invasive potential and can cause many problems to the ecosystem (Cohen, 2011; Fransen, 2015; IUCN, 2013).

Lutjanus kasmira **(Forsskål, 1775):** is associated to reefs and has a depth range of 3-265m and a temperature range of 20°C - 28°C. This species can be found during the day in large aggregations in reef areas, or caves and the juveniles can be are found in grasslands near reefs (Froese & Pauly, 2015). Its native distribution is in the Indo-Pacific, the Red Sea and East Africa, Marquesas Islands, northern and southern Japan, south of Australia, southeast Atlantic and Southern Africa. Introduced to Hawaii from the Marquesas Islands in 1955 (Friedlander *et al.* 2002) or 1958 (Froese & Pauly, 2015). Its introduction was through secondary spread (in local areas) and marine currents. It has been introduced intentionally for recreational purposes (sport fishing) and food. In Hawaii, this species shares the same habitat than other species of native snappers, Gender *Mulloidichthys*, which results in direct competition for food and habitat resources. The displacement of native populations of snappers has been documented due to the pressure of the introduced species *L. kasmira*. Additionally, the intentional introduction of this species in Hawaii has decreased fishing for other local species (Bailly, 2015a; IUCN, 2013).

Pterois volitans **(Linnaeus, 1758):** Inhabits tropical marine water with temperature ranging between 22°C - 28°C. Lower temperature ranges have been observed in U.S. (14°C to 24°C). The depth range for this species is 10 to 175m. Red lionfish will favour coral reefs and rocky outcrops although it has been observed in coral patches, sandy bottoms, mangroves, seagrass habitats and even habitats in the Canal. It is widely distributed throughout the Western Pacific and most of Oceania east of French Polynesia (Morris & Whitfield, 2009; Hare & Whitfield, 2003) *P. volitans* has invaded the Atlantic coasts of the U.S. and the Caribbean (Morris & Whitfield, 2009; Gonzalez *et al.* 2009). The areas that are currently most affected are the southeast coast of the United States, Bermuda and the Bahamas, this is due to the establishment of this species before 2005 (Hare & Whitfield, 2003; Schofield, 2009) Pelagic juveniles move over great distances explaining the geographical range of lionfish (Froese & Pauly, 2015).The natural dispersion of lionfish probably occurred during the pelagic larval stage in which larvae disperse over long distances; for example, eggs released in the Bahamas can be dispersed to New England through the Gulf Stream (Morris & Whitfield, 2009). Ballast water is another possible vector for dispensation it can transport the eggs and larvae from one region to another (Whitfield *et al.* 2002). *P. volitans* is a voracious predator, it is a danger to local residents, tourism and for some fisheries. It reduces the recruitment of young fish, which in turn disrupts marine ecosystem processes and reduces reef biodiversity (Albins & Hixon, 2008; Morris & Whitfield, 2009). It has the potential to severely reduce the biodiversity of the reef, with the possible extinction of several species. In addition, to reduce populations of commercially important species such as grouper (Albins & Hixon, 2008) it can damage the economy as a lot of the communities rely on the fishing industry. *P. volitans* has poisonous spines venomous and can be dangerous for divers and aquarium enthusiasts (Bailly, 2015b; Morris & Whitfield 2009; Schofield 2009).

2.12 Management and risk assessments

During this review, the challenging difficulties of managing marine non-native species have been highlighted, and several different species have been discussed indicating the potential problem the GMR could face if those species arrive and/or become established. In order to help local stakeholders, risk assessment tools need to be developed to provide knowledge in case an invasion occurs.

An efficient policy to support conservation and social sustainability must act on the connections between Galapagos, continental Ecuador, and the rest of the world, to reduce the flows of non-native species that enter the archipelago (Grenier, 2010). The management of incoming vessels and adequate quarantine protocols need to be put in place. The inspection protocols have to be extended beyond the GMR, to the last port of call or beyond, all boats should arrive to the Galapagos with clean hulls and be re-inspected upon arrival.

It is uncertain how these species might respond to climate change or climate variability, which is why these species have been placed on a priority 'watch list'. The Charles Darwin Foundation (CDF), the Galapagos National Park Directorate (GNPD) and the Ecuadorian Biosecurity Agency (ABG), have established monitoring programs in order to keep an eye on these species spreading or causing further impacts to the GMR. There are several potential high-risk species that could damage the marine ecosystems of the Galapagos Islands. Some of these species have been identified by Campbell & Hewitt (2007), and more investigation is being undertaken currently. It is a priority to establish what the high-risk species are for the GMR in order to improve management protocols for marine invasive species. Prevention, early detection and rapid response protocols have to be put in place along with risk assessments and management strategies.

The islands in the north of Scotland (Orkney and Shetland) have over the years developed several biosecurity plans to reduce the potential introduction of non-native species and minimize any impacts. These islands have been under threat from bioiunvasions for years from marine traffic, aquaculture and secondary dispersal. The management plans that have been put in place are examples to follow (Collin *et al.* 2015). Similarly the Hawaiian archipelago has over the years received some major bioinvasions an example being Carijoa riisei (Kahng & Grigg, 2005) the impact these bioinvasion have caused the marine habitat is high and management plans have been put in place to the extent that some northern islands have been closed off completely to foreign vessels, management strategies are important to be able to prevent and control invasions (Simberloff *et al.* 2013).

Chapter 3:

Establishing baseline inventory of non-native species for the GMR

3.1 Introduction

This chapter introduces the research methodology used for this study, the design suitability and discussion. A compilation of historical literature was gathered for non-native species reported in the Galapagos, with some of these records dating back to the Allan Hancock Pacific Expeditions conducted in the early 30s (Taylor, 1945). In addition monitoring surveys were undertaken in the main ports of the archipelago, in selected sites around the GMR, and in protected bays and mangrove areas to assess the presence of non-native species in the GMR at the present time and create a baseline inventory of non-native marine species in the GMR.

The species reported in the literature were then investigated further, looking at (a) their current native and introduced distribution, (b) their invasive capacity and whether the species has demonstrated invasive behaviour in other parts of the world, (c) if the ecological conditions are suitable in the GMR for the species to proliferate, and (d) if the species could have been transported by one of the dispersion vectors affecting the GMR. The distributions of these species were determined using the Global Invasive Species Database (ISSG, 2015), the World Register of Introduced Marine Species (Pagad *et al.* 2015), World Register of Marine Species (WoRMS, 2015b) and Algaebase (Guiry & Guiry, 2015a). Records of these species presence where also checked on the CDF marine database that holds records of all species reported in the GMR and their distribution (Bungartz *et al.* 2009).

3.2 Historical monitoring systems in the GMR

The GMR was established with the aim of achieving the conservation and protection of marine biodiversity, ensure the sustainability of economic activities and standardize and regulate human activities (DPNG & FCD, 1999). The original zoning proposal was based on the creation of different management zones to ensure the protection of marine biodiversity through no-take zones within the different regions and existing habitats in the archipelago (Heylings *et al.* 2002). However, when allocating such areas there was very little information on the abundance and distribution patterns of species, therefore, a baseline study for the biodiversity of the GMR was initiated in 2000, to establish conservation priorities by identifying sensitive areas of high biodiversity and endemism and to re-evaluate the biogeographic regions proposed by Harris (1969) (Figure 3.1). The monitoring focused on three taxonomic groups: demersal fish, mobile macroinvertebrates and sessile organisms, all exposed to the outer surface of the rock and within the range of visibility of the divers (Banks *et al.* 2004).

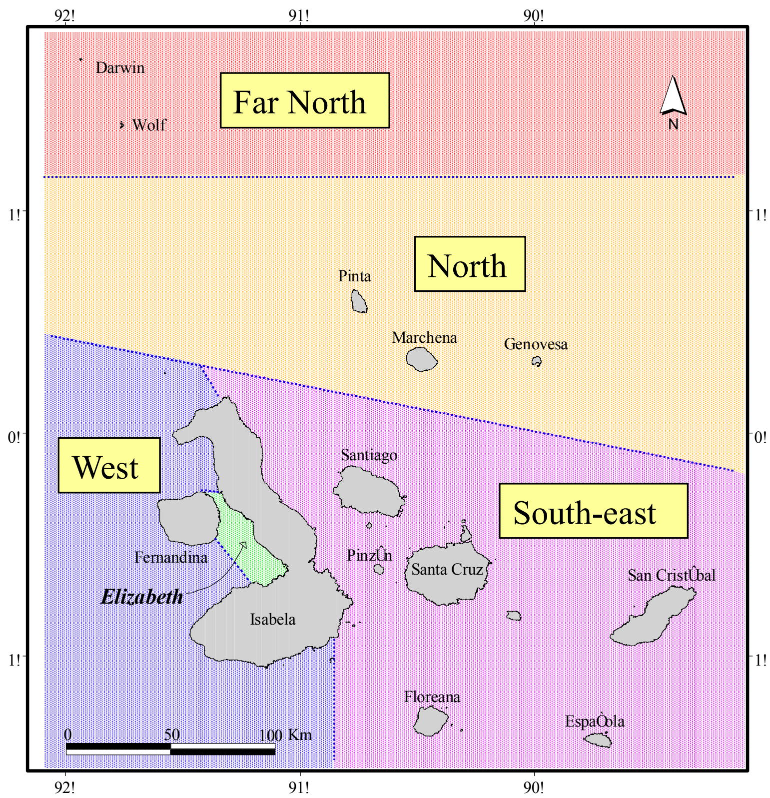


Figure 3.1: Bioregions of the Galapagos Marine Reserve based on Harris, 1969.

Since the baseline study that concluded in 2001, annual ecological monitoring programs have been conducted by CDF-Marine staff in order to: i) determine the abundance, distribution and natural variation limits of communities and coastal marine species present in the GMR, ii) provide a means to distinguish the effects of human activities and natural variability, iii) identify unnatural agents that generate abnormal conditions in communities and coastal marine species (e.g. introduced species, pollution) and iv) evaluate in a systematic and ongoing way the development of human activities, include both extractive and non-extractive activities (Banks *et al.* 2004).

3.3 Methodology

The methodology described in this chapter makes reference to the baseline survey for marine non-native species in the GMR. The surveys were conducted in different sites around the archipelago, marine ports and protected bays (Appendix III) over a period of 3 years (Table 3.1). This research was done alongside the CDF's ecological monitoring program to take advantage of monitoring trips and to share costs.

Table 3.1: Dates of monitoring trips conducted

Date of monitoring trips		Region
25/06/12	30/06/12	West and East
11/02/13	15/02/13	South and East
07/04/13	12/04/13	West
07/05/13	11/05/13	North
20/02/14	26/02/14	West
24/03/14	29/03/14	South and East
29/06/14	07/07/14	North
12/04/14	18/04/14	West
19/03/15	29/03/15	West
05/05/15	14/05/15	North

3.3.1 Subtidal monitoring

There are around 380 sites (Appendix II) that have been monitored as part of the GMR baseline, and these are documented in the CDF marine database (Bungartz *et al.* 2009). In 2004, the DPNG led a process to signal all the coastal subzones in the GMR for management purposes, during this time the design of an annual subtidal monitoring program run by CDF was finalised. This program is based on the repetition of monitoring 64+ sites around the GMR, each site has three zones marked, tourism, fishing and protection. (Banks *et al.* 2014). The sites chosen for this study were based on the sites monitored in the past in the GMR in order to have a reference of the species recorded previously.

115 sites were surveyed (Appendix II), (Figure 3.2) using a proven standardised methodology developed by the CDF for long-term evaluation of subtidal communities in the GMR; this methodology is also applied in other marine protected areas in the ETP (Banks *et al.* 2014). This methodology focuses primarily on recording the diversity, abundance and size of the species present in three major groups of macro fauna: fish, macro invertebrates and sessile organisms. Each sample consists of divers moving along a 50m transect parallel to the coast where visual censuses are conducted for the three taxonomic groups, this is done at a depth of 15m and 6m.

Figure 3.2: Map illustrating the monitoring sites around the archipelago

The fish monitoring consists of identifying the levels of species richness, measuring the population density, determining the size structure of each species and conducting a visual inspection for non-native species. An area of $500m^2$ is monitored by a diver who swims along the transect considering an imaginary corridor of 5m wide x 5m high x 50m long, parallel to the transect. The mobile macroinvertebrate monitoring focuses on simultaneously measuring the density and abundance of several species at a time, including commercial, non-commercial and non-native species. An area of 100 m^2 is monitored along the same 50m transect, the diver swims along in 5m segments considering a 1m strip at either side of the transect recording the number of invertebrates larger than 2cm. Sessile organisms are an important component of marine communities. Due to their sedentary lifestyle, sessile organisms are good indicators of local conditions, long-term physical changes, biological changes and any effects that can be produced by natural phenomena or human-caused disturbances. Their presence or absence is a good indicator of biological and abiotic processes prevailing, such as competition, interactions with predators or prey or large-scale effects such as current circulation patterns, recruitment events, temperature, or marine invasions. An area of 2.5 m^2 is monitored using a PVC quadrant of 0.5 x 0.5m ($0.25m^2$). Each quadrant has a grid of 5 x 5cm constructed with polypropylene twine with 81 intersection points to determine the abundance of each species. Quadrants are placed systematically every 5m along the same 50m transect. In each quadrant all species that fall in the 81 intersections must be counted and recorded, species that do not fall in the intersections recorded as present (Banks *et al.* 2014). Various samples were collected for later identification or were sent to taxonomic experts to confirm identification or to conduct DNA studies.

3.3.2 Port monitoring

There are five populated islands in the archipelago (Figure 3.3), each with a main dock and several smaller docks: i) Puerto Baquerizo Moreno, on the Island of San Cristobal, ii) Puerto Ayora, on the Island of Santa Cruz, iii) Puerto Villamil, on the Island of Isabela, iv) Puerto Velasco Ibarra, on the Island of Floreana and v) Puerto de Seymour, on the Island of Baltra. There are several different components in the port monitoring methodology. Each port has a different layout, and each has a different number of docks that require inspecting. Permission to inspect the docks was obtained from the port authority as the ports are heavily visited by marine traffic, and health and safety protocols need to be followed. The monitoring of the docks was done through visual inspection, all species present were recorded, scrapings from the docks walls or pylons were taken for later identification in the laboratory, and video transects were recorded for comparative analysis.

Two divers conducted the visual inspection, one recorded all fish and macroinvertebrates in the surrounding dock area, and the other diver recorded the percentage cover of sessile organisms. The area surveyed was the total area around the dock starting at the shallowest depth possible for divers. The area covered varied on each dock, as the size of each dock was different. Sessile organisms were recorded using a PVC quadrant of 0.5 x 0.5m (0.25m^2) (Banks *et al.* 2014), and records were taken at three depths (e.g. 0.5m, 3m, and 7m). In addition, scrapings were collected at the same three depths as the sessile survey for later identification in the laboratory. A video transect was recorded of all areas surveyed by the divers including the areas where scrapings were taken. Photographs of potential non-native species that were present around the docks were also recorded to facilitate later species identification. During port monitoring, mooring buoys and/or navigation buoys were also inspected. The buoys consist of different parts, the marker buoy floating on the surface of the water, the chain and cement block on the sea floor. Visual inspections to all these areas were conducted, recording all species present. Scrapings of the base of the buoy were taken for later identification, and a video recording of the marker buoy, the chain and the cement block was recorded. The area surrounding the cement block was also inspected for non-native species.

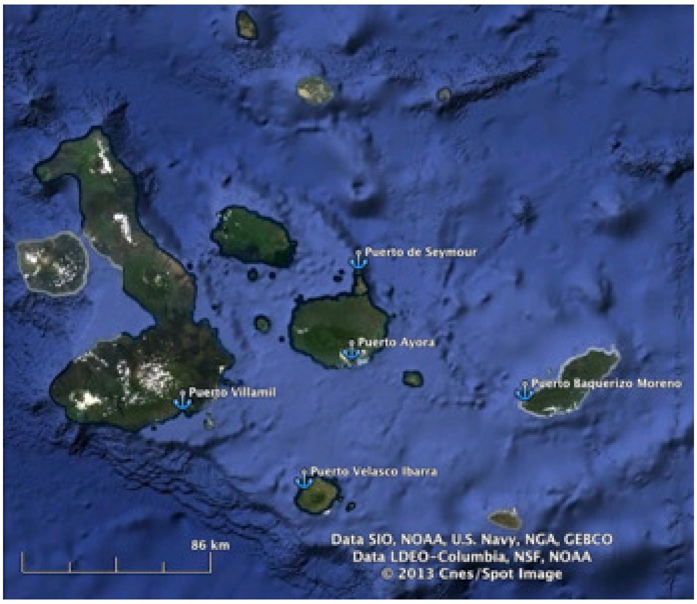


Figure 3.3: Map illustrating the five main ports that were monitored in the GMR

3.3.3 Protective bays and mangrove monitoring

The Galapagos Islands have many protected bays, with the majority located on the western islands of Isabela and Fernandina. A separate monitoring technique was developed for these areas, as these bays are small in size, shallow, have very low wave exposure, and hence, diving is not necessary. The monitoring of these bays were undertaken through directed searches for non-native species using snorkelling apparatus. A list of potential non-natives used for the identification of species during the directed searches was compiled from literature collected on marine invasive species worldwide. Photographs and samples of specimens were collected for later identification in the laboratory. The many bays of the archipelago support a number of mangrove habitats, where visual inspections of the intertidal zone of the mangroves were conducted in order to evaluate the presence of non-native species.

3.3.4 Settlement plates

An additional method was applied to the main port of Santa Cruz. It was decided that a pilot project would begin as part of this research to study the fouling communities on port structures in more depth. The methodology applied was from the Smithsonian Environmental Research Center (SERC), USA and the Smithsonian Tropical Research Institute (STRI) in Panama. BY using the same methodology as

SERC and STRI the results from the GMR can be compared to those in Panama and the USA. Unfortunately, the final results of this pilot project will not be gathered until April 2016, however, preliminary results were obtained and are showcased after the methodology is explained in this section.

Two sites where chosen for this research i) the main dock in the town of Puerto Ayora and ii) two passenger docks in Franklins Bay.The dock in Puerto Ayora is characterised by a concrete “Y” structure with four floating pontoons on the side, two on either side (Figure 3.4). The main dock was chosen as a site because of the high levels of marine traffic that uses this dock and this site is located in an open bay. The docks at Franklins bay are smaller and have one floating dock eachThe docks are used by smaller tourist boats and private boats and they are located in a more sheltered bay.

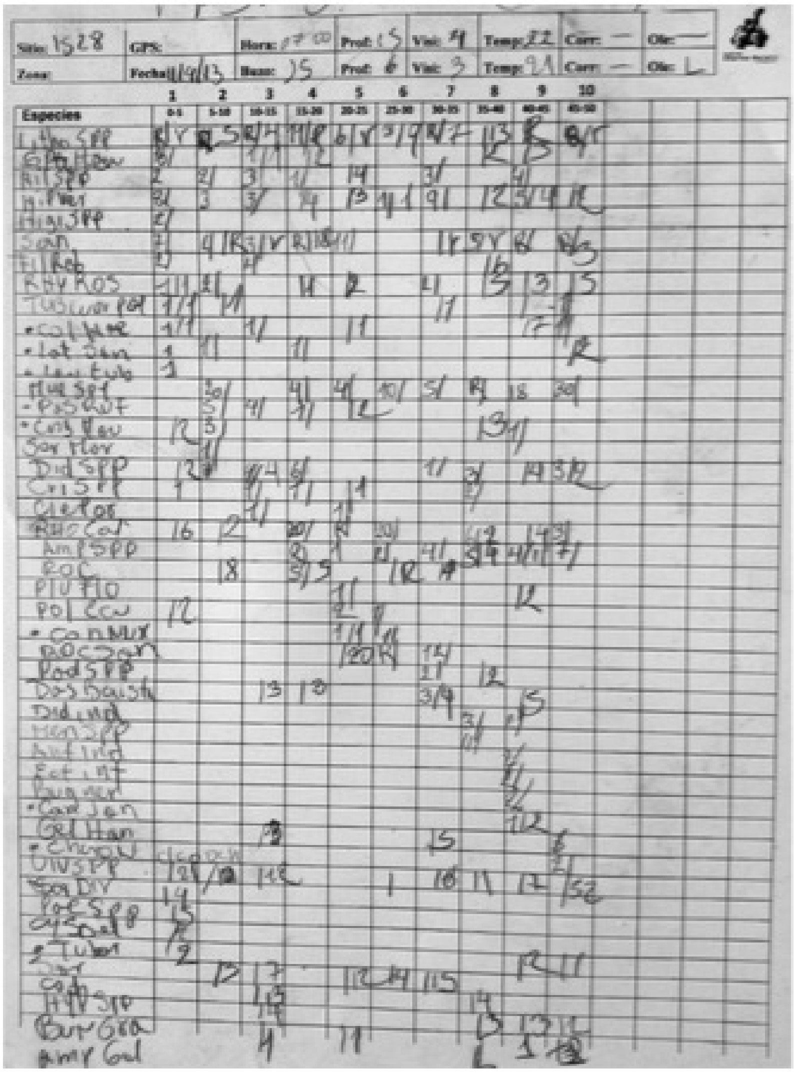
Figure 3.4: Main dock in Puerto Ayora, Santa Cruz Island

A total of 30 settlement plates were deployed at these sites. The plates are made of PVC plastic and have a weight on the top so that they hang facing the seabed. Each plate is hung from the dock allowing enough rope (+/- 1m) for the plates always to be in the water with the change of tide. For this research plastic mesh cages were also added to half the sample in order to protect them from predation and compare results with the plates that are not protected by the cages.

3.4 Results for Non-Native Species in the Galapagos Marine Reserve

The results obtained from conducting the marine surveys detailed above are presented in the following section along with the new records that this research has found. The current list of established non-native species and their distribution in the GMR is presented along with a discussion of the current behaviour these species exhibit at the moment in the GMR and the possible risks associated with these species. Furthermore, this section illustrates the importance of using various surveying methods to cover different habitats in order to record the highest number of species and finishes by discussing and comparing each method and what other methods could be used in the future.

The data from this research was logged on underwater paper by the divers (Figure 3.5) and then transferred to excel sheets (Figure 3.6) and analysed before being uploaded to the Charles Darwin Foundationsmarine database (Figure 3.7). The species lists were also uploaded to theCharles Darwin Foundations centralized database-datazonehttp://datazone.darwinfoundation.org. In the case of sessile organisms the excel sheets analysed the total intersections of each quadrant in order to reach a maximum of 81 as seen in figure 3.6. Using the same example it can be noted that in that one site two marine non-native species were recorded. Appendix II shows the location and the year where each non-native species was recorded.


Sitio: 1528 | GPS: | Hora: 17:00 | Prof: 15 | Vis: 4 | Temp: 22 | Corr: — | Ola: —
Zona: | Fecha: 11/9/13 | Buzo: JS | Prof: 6 | Vis: 3 | Temp: 21 | Corr: — | Ola: L

Especies | 1 0-5 | 2 5-10 | 3 10-15 | 4 15-20 | 5 20-25 | 6 25-30 | 7 30-35 | 8 35-40 | 9 40-45 | 10 45-50

Figure 3.5: Example of divers data sheet

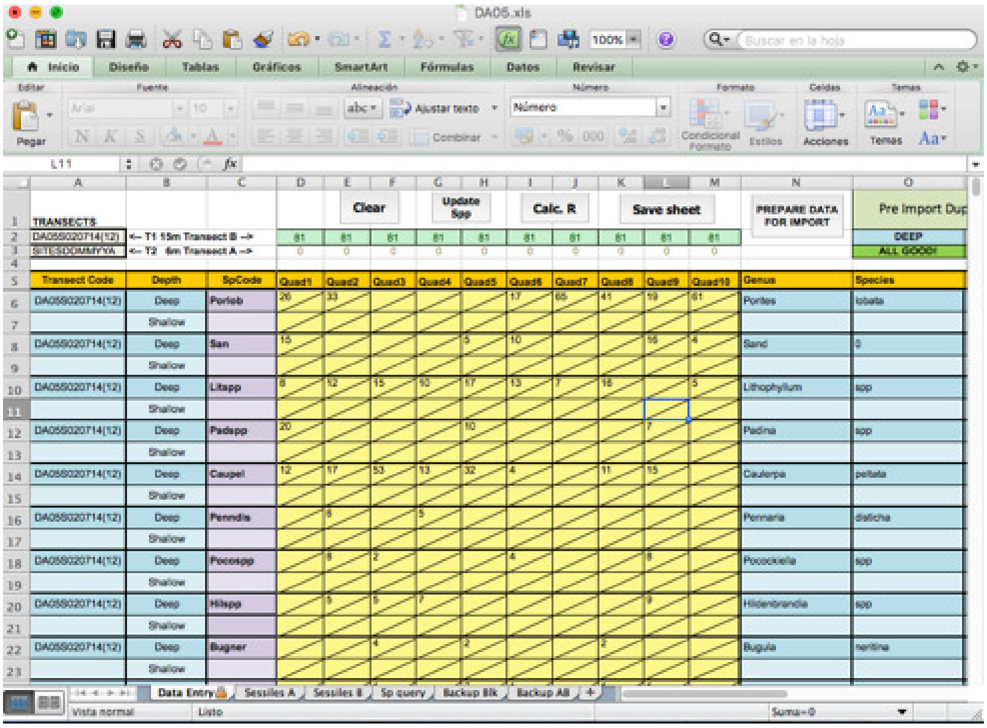


Figure 3.6: Excel sheet (exaple of sessile organisms) two non-native species can be seen on this sheet*Pennaria disticha* (Pendis) and *Bugula neritina* (Bugner)

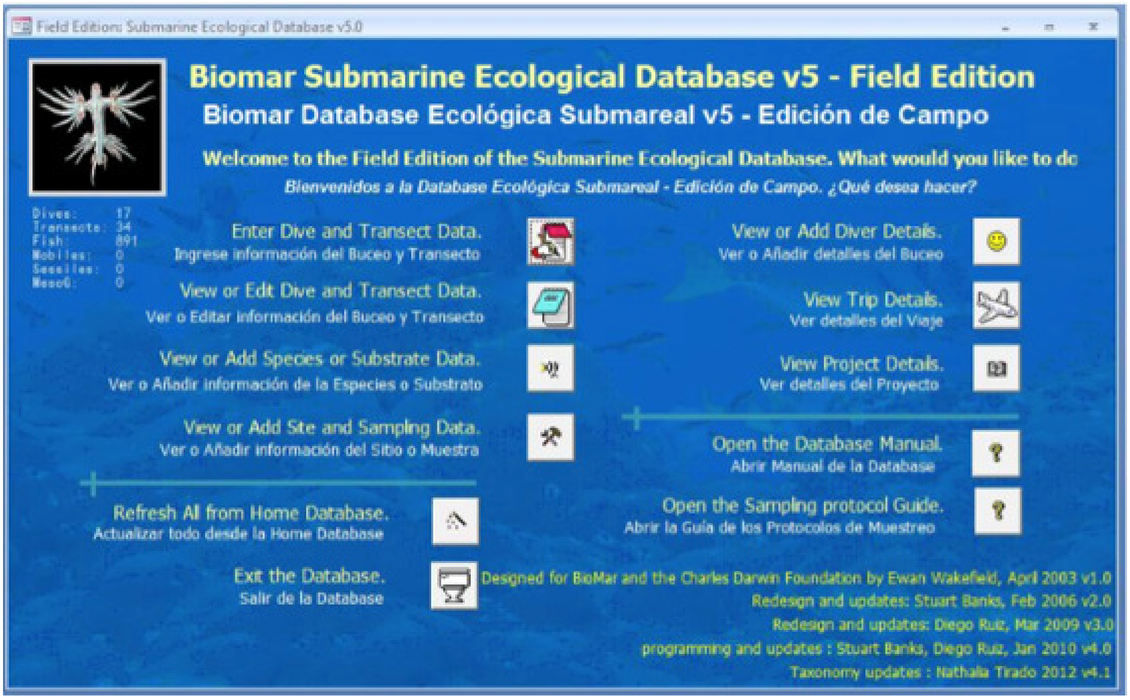


Figure 3.7: Front page of the Charles Darwin Foundations marine database

3.4.1 Marine survey results

In contrast with the literature search discussed in chapter 2, the diving expeditions conducted since 2012 produced a list containing six out of the seven previously reported species in the literature and three new records for the GMR (Table 3.2). *Schizoporella unicornis* is classed as introduced and naturalized by the CDF Checklist (Bungartz*et al.* 2009) but there has been no record of this species since Osborn reported it as present in the 1930's (Taylor, 1945), this species was not found during the yearly ecological monitoring surveys carried out by CDRS since 1997 (Bustamante *et al.* 2000; Danulat & Edgar, 2002) or by searches conducted in this research. For this reason, it has not been put on the list of non-natives present in the GMR at this time. The first new record that this research produced was *Amathia verticillatum,* commonly known as the spaghetti bryozoans (McCann *et al.* 2015). The other two new non-native species found in the GMR are the ascidians *Botrylloides pizoni* and *Botrylloides nigrum* (Jonathan Geller, Melinda Wheelock and Linda McCann, personal communications, November 2015). With the information recorded the distribution of the nine species identified as non-native in the GMR were mapped (Figure 5.10).

Table 3.2: Non-native species recorded in the GMR

Phylum	Family	Scientific name	Common name
Chlorophyta	Caulerpaceae	*Caulerpa racemosa*	Grape algae
Rhodophyta	Bonnemaisoniaceae	*Asparagopsis taxiformis*	Red sea plume
Arthropoda	Gecarcinidae	*Cardisoma crassum*	Blue crab
Bryozoa	Bugulidae	*Bugula neritina*	Brown bryozoan
Cnidaria	Pennariidae	*Pennaria disticha*	Christmas tree hydroid
Echinodermata	Acanthasteridae	*Acanthaster planci*	Crown of thorns
Bryozoa	Vesiculariidae	*Amathia verticillata*	Spaghetti Bryozoan
Chordata	Styelidae	*Botrylloides pizoni*	Sea squirt
Chordata	Styelidae	*Botrylloides nigrum*	Sea squirt

The different methods used to search for non-native species has enabled the coverage of a wider range of habitats than if only one method had been utilized, likely resulting in more species now being identified (Table 3.3). The subtidal monitoring was essential because this method allowed searching for species at different depths. The monitoring of the main ports in the region was of great importance and considered high priority, as these are the most likely areas where possible invaders can arrive due to the marine traffic from abroad and continental Ecuador. The protected bays provide excellent habitats for certain species to established, reproduce and compete with native species due to particular environmental conditions, such as water temperature, depth, visibility and low wave exposure, that favour certain categories of non-native species.

Table 3.3: Non-native species found using different survey methodologies

Scientific name	Subtidal	Ports	Protected bays and mangroves
Caulerpa racemosa			X
Asparagopsis taxiformis	X	X	
Cardisoma crassum			X
Bugula neritina	X	X	
Pennaria disticha	X		
Acanthaster planci	X		
Amathia verticillata		X	X
Botrylloides pizoni		X	
Botrylloides nigrum		X	X

The macro fauna and flora were identified in situ although photographs and samples were taken for morphological identification in the laboratory to confirm the identification. In the case of small organisms like the ascidians, samples were collected and processed for barcoding and sent to Dr. J. Geller at the Moss Landing Marine Laboratories. Results were received for two ascidian species: After trimming and BLASTing, one sample was a 99.6% pairwise (GenBank) match to *Botrylloides pizoni*, and one sample matched 99.6% to *Botrylloides nigrum*(Jonathan Geller, Melinda Wheelock and Linda McCann, personal communications, November 2015).

3.4.2 Settlement panels

Preliminary results have already shown non-native species growing on the plates (Figure 3.8). This ascidian *Botrylloides nigrum* is a common fouling organism that is considered non-native for the ETP region. In April 2016, a team of expert taxonomists will be visiting the Charles Darwin Research Station (CDRS) to analyse these plates. The results are expected to be interesting, and new records are expected to come from this plate analysis.

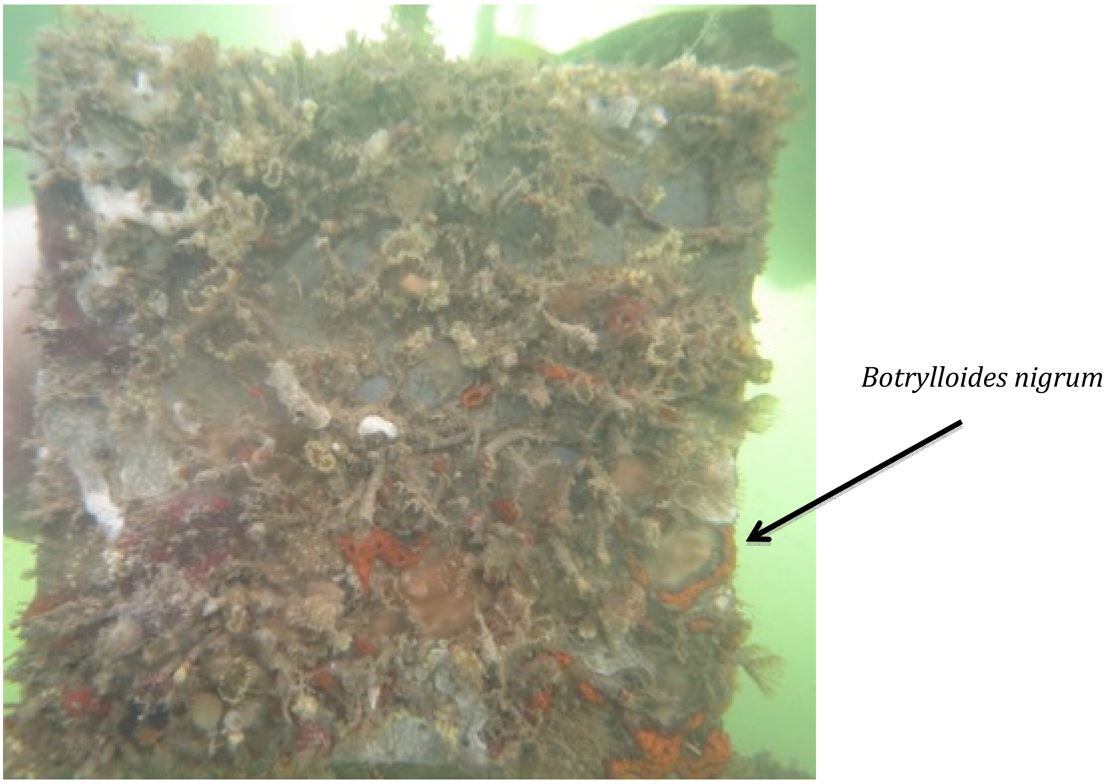


Figure 3.8: Settlement plate illustrating the non-native species *Botrylloides nigrum*©Inti Keith

3.4.3 Fact sheets of non-native species found in the GMR

The following section illustrates the fact sheets for the nine marine non-native species found in the GMR at this time. Each fact sheet contains a description of the species, a photo taken in situ (except for *B. pizoni*), the species habitat, the impacts the species can cause and their known distribution.

I. *Caulerpa racemosa* (Forsskål) J.Agardh, 1873

Figure 3.9: *Caulerpa racemosa,* Fernandina Island

Description: Small light green algae, that consists of small creeping stolons that have small rhizoids that can fix to the substrate and has erect fronds that can form similar to a bunch of grapes and form dense mats that can cover large areas.

© Noemi d'Ozouville

Habitat: Intertidal, shallow reefs and tropical waters

Impacts: Its growth hampers the exchange of oxygen and displaces other species

Distribution: The native distribution for this species is Australia, and its present distribution is fairly global: Europe: France, Greece, Cyprus, Italy and Turkey. USA: Florida. Central America: Revillagigedo Islands, Mexico (Pacific), Panama, Veracruz. Caribbean Islands: Bahamas, Cuba, and Martinique. West Atlantic. South America: Brazil, Galapagos Islands and Venezuela. Africa: Kenya, Mauritius and Tanzania. Indian Ocean: Nicobar Islands and Seychelles. Asia: Bangladesh, India, Pakistan, China, Japan, Indonesia, Philippines, Singapore, Thailand and Vietnam. New Zealand, Australia and Papua New Guinea.

(Eldredge & Smith, 2001; Farlow, 1902; Guiry, 2015b; Klein & Verlaque, 2008; Molnar *et al.* 2008; Ruiz & Ziemmeck, 2014; Taylor, 1945).

II. Asparagopsis taxiformis (Delile) Trevisan de Saint-Leon, 1845

Description: Delicate feathery red algae, the fissures are arranged in a pyramid form, the algae adheres to the substrate using fine rhizoids

Figure 3.10: *Asparagopsis taxiformis,* Fernandina Island ©Inti Keith

Habitat: Tropical and subtropical rocky substrates

Impacts: It can spread fast forming dense colonies displacing other native species.

Distribution: It is native in the Indo-pacific, Australia, New Zealand and Chile. This species is present in the Atlantic, Pacific and Indian Oceans, the Mediterranean.

(Chualáin *et al.* 2004; Dawson, 1963; Guiry, 2015c; Ruiz & Ziemmeck, 2014; Taylor, 1945).

III. Cardisoma crassum Smith, 1870

Figure 3.11: *Cardisoma crassum,* Santiago Island©Lillian Catenacci

Description: Thecarapace is oval, it is wider rather than longer and it has a blue-cream colour. It has red legs and white-cream pincers; one of the pincers is larger than the other.

Habitat: Found in mangrove areas, where it builds its burrows, its reproductive cycle occurs in the ocean.

Impacts: The impacts of this species have not been studied but it is thought they compete for space with other invertebrates.

Distribution: The native distribution of this species is along the Central and South American Pacific coast from Baja California to Peru. The present distribution is as above with the addition of the Galapagos Islands

(Bright, 1966; Causton *et al.* 2011; Davie, 2015; Fischer *et al.* 1995; Garth, 1991; Hickman, 1997).

IV. Bugula neritina (Linnaeus, 1758)

Description: Colonial animal with branching tufts, purple in colour. It can often be mistaken for algae.

Figure 3.12:*Bugula neritina,*Bartolomé Island ©Inti Keith

Habitat: Benthic and intertidal, coral reefs, marine ports

Impacts: Fouling organism

Distribution: Its native distribution range is uncertain but it is thought it is native in the Mediterranean. In many regions it is considered an introduced species, despite being recorded since the early twentieth century. It has a broad global distribution in temperate, subtropical and tropical waters, including the Red Sea (reported in 1909, India (reported in 1971), Japan (reported in 1960), China (reported in 1986), Hong Kong (reported in 1977), several sites around Australia (reported in Port Phillip Bay in Victoria in 1881, in South Australia in 1982, and in New South Wales in 1993), New Zealand (1949), Hawaii (collected in 1921), the Pacific coast of Mexico (reported in 1950), the Galapagos Islands (reported in 1930), the Magellanic Islands (reported in 1991), on both coasts of Panama (reported in the Canal Zone in 1930, and common on both coasts in 1971), Long Island Sound (collected in 1993), North Carolina (reported in 1940), Bermuda (reported in 1900), Florida (reported in 1947), the Tortugas Islands (collected in 1914), Puerto Rico (reported in 1940), Curacao (reported in 1927), Brazil (reported in 1937), Argentina (reported in 1943),southern England (reported in the heated effluent of power plants in 1912) and the Mediterranean Sea.
(Taylor, 1945; Eldredge & Smith, 2001; Gordon, 2015; Ryland *et al.* 2001; Molnar *et al.* 2008; Vieira *et al.* 2012).

V. Pennaria disticha Goldfuss, 1820

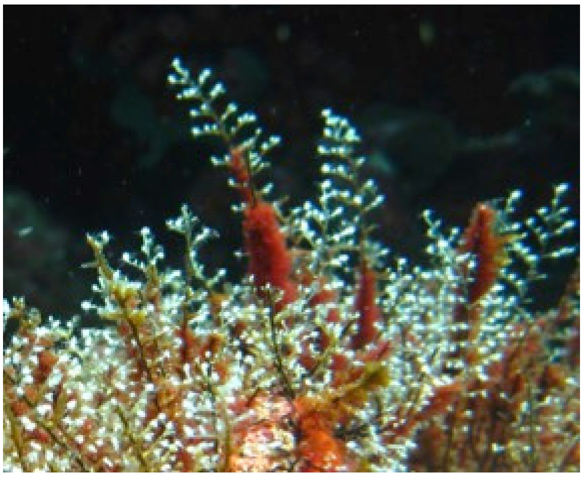


Figure 3.13: *Pennaria disticha,* Bartolomé Island
©Inti Keith

Description: Large colonies as tall as 30cm, colonies have numerous polyps that extend upward from the branches. The branching is alternate and the polyp has tentacles at the base, which are white in colour.

Habitat: Rocky and coral reefs, this hydroid adheres to hard substrates natural or artificial.

Impacts: Common fouling organism, competes with other invertebrates

Distribution: The native distribution for this species is the West Atlantic Ocean and its present distribution includes Hawaii, New Zealand, East Coast of USA and Galapagos.

(Danulat & Edgar, 2002; Eldredge & Smith, 2001; Hickman, 2008; Molnar *et al.* 2008; Schuchert, 2015; Taylor, 1945).

VI. *Acanthaster Planci* (Linnaeus, 1758)

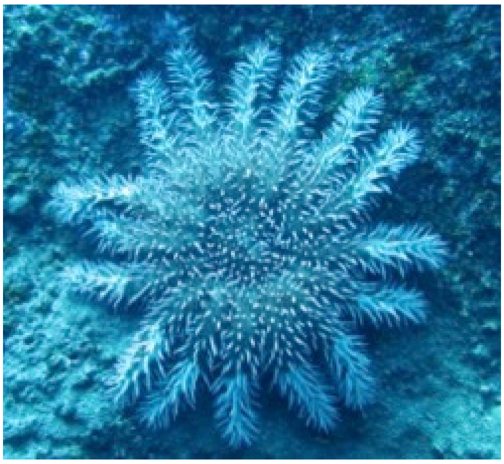


Figure 3.14: *Acanthaster planci*, Darwin Island©Inti Keith

Description: Orange and pink in colour with white poisonous spines that cover the surface of the arms and central disk. It has between 10-14 arms they are generally between 25-35 cm in diameter but can grow up to 80cm.

Habitat: Coral reefs

Impacts: Threat to coral reefs as it feeds on the corals and kills them

Distribution: It is native to the Indo-pacific and is now found in Hawaii, Palau, Guam, Great Barrier Reef (Australia), Japan, Micronesia, Samoa, Cocos Islands, Fiji, Maldives, Malaysia and the Galapagos Islands.

(Cohen-Rengifo *et al.* 2009; Hickman, 1998; Mah, 2015a)

VII. *Amathia verticillata* (delle Chiaje, 1822)

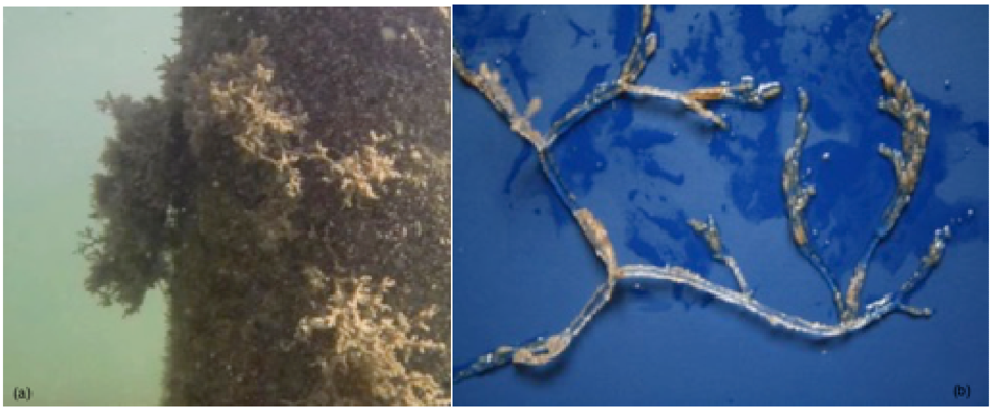


Figure 3.15: (a)*Amathia verticillata* on pier at Franklins bay©Inti Keith. (b) *Amathia verticillata* colonies from Tortuga bay ©Linda McCann.

Description: This bryozoan is commonly referred to as the spaghetti bryozoan due to its un-calcified body that forms colonies with irregular branching stolons with zooids attached, giving it the appearance of gelatinous noodles. It is a well-known fouling organism, it currently has a widespread distribution in tropical and warm-temperate waters around the world (Fofonoff *et al.* 2003; McCann *et al.* 2015).

Habitat: Found on rocks, wood, marine port structures and boat hulls (Fofonoff *et al.* 2003)

Impacts: It can cause hull fouling, block intake pipes on vessels and foul fishing gear. In the GMR if this species was to become abundant and widespread it could cause environmental and economic impacts (McCann *et al.* 2015)

Distribution: The native distribution of this speciesremains uncertain, however both the Mediterranean Sea and the Caribbean Sea have been suggested as the native regions for this species (Carlton & Eldredge, 2009; McCann *et al.* 2015). This species has a worldwide-introduced distribution including new records from the Azores, Madeira, and Canary Islands, Western Atlantic Ocean, eastern Mediterranean and Palmyra Atoll in the Pacific Ocean (Amat & Tempera 2009; Wirtz & Canning-Clode, 2009; Knapp *et al.* 2011; Minchin, 2012; Tilbrook, 2012; Galil & Gevili, 2014; Ferrario *et al.* 2014).

VIII. Botrylloides pizoni (Brunetti & Mastrototaro, 2012)

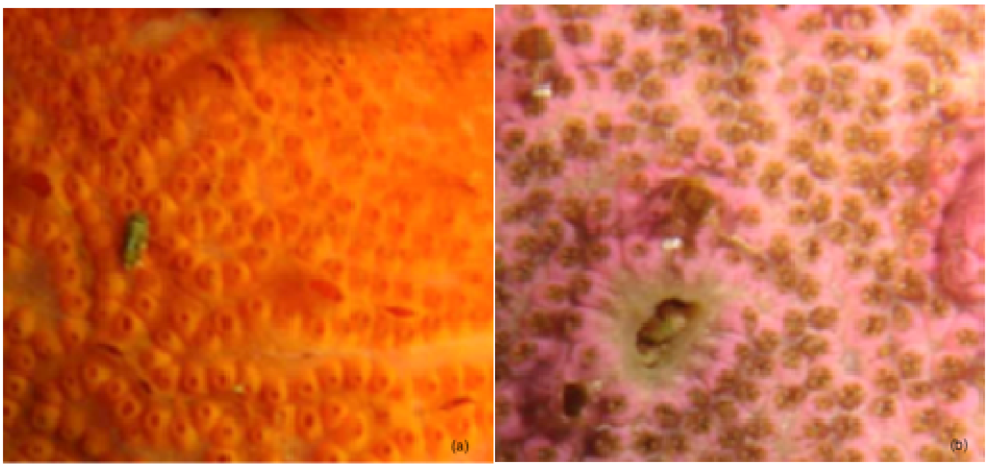


Figure 3.16: (a and b)*Botrylloides pizoni* (Brunetti & Mastrototaro, 2012)

Description: Live colonies are mainly violet but red and orange colonies exist as well. This species has large zooids arranged in ladder systems. The zooids have several rows of stigmata, the testis and ovary lie below the buds and the ovary is posterior to testis, one larva per side developing in an incubatory pouch, and a peculiar arrangement of the gut loop that counts with eleven folds (Brunetti & Mastrototaro, 2012).

Habitat: Found on rocks, wood, large brown algae, marine port structures and boat hulls

Impacts: Fouling organism

Distribution: First reported from the Mediterranean Sea, introduced to the Galapagos Islands.

IX. Botrylloides nigrum (Herdman, 1886)

Figure 3.17: *Botrylloides nigrum*, Punta Espinoza ©Inti Keith.

Description: Colonies can be distinguished easily for their orange horseshoe shape that connects the siphons against a dark purple background. The zooids have approximately 12 rows of stigmata and 9-10 folds on the stomach wall (STRI, 2011).

Habitat: Found on rocks, wood, marine port structures and boat hulls

Impacts: Fouling organism

Distribution: Florida, Bermuda, Bahamas, Puerto Rico, Haiti, Jamaica, Cuba, Guadalupe, Bonaire, Curaçao, Marguerita, Aruba, St, Martin, Martinica, Colombia, Brazil, Senegal, Sierra Leone, Somalia, Morocco, Cape Verde, Angola, South Africa, Madagascar, Australia, Polynesia, Mariana Is., México (STRI, 2011; Moreira & Sanamyan, 2015b), introduced to the Galapagos Islands

3.5 Distribution of non-natives species in the GMR

The previously mentioned species are illustrated in the map bellow (Figure 3.18). Each coloured dot represents one of the above-mentioned non-native species. The distribution of the species where plotted only after a positive identification of each species in the Laboratory.

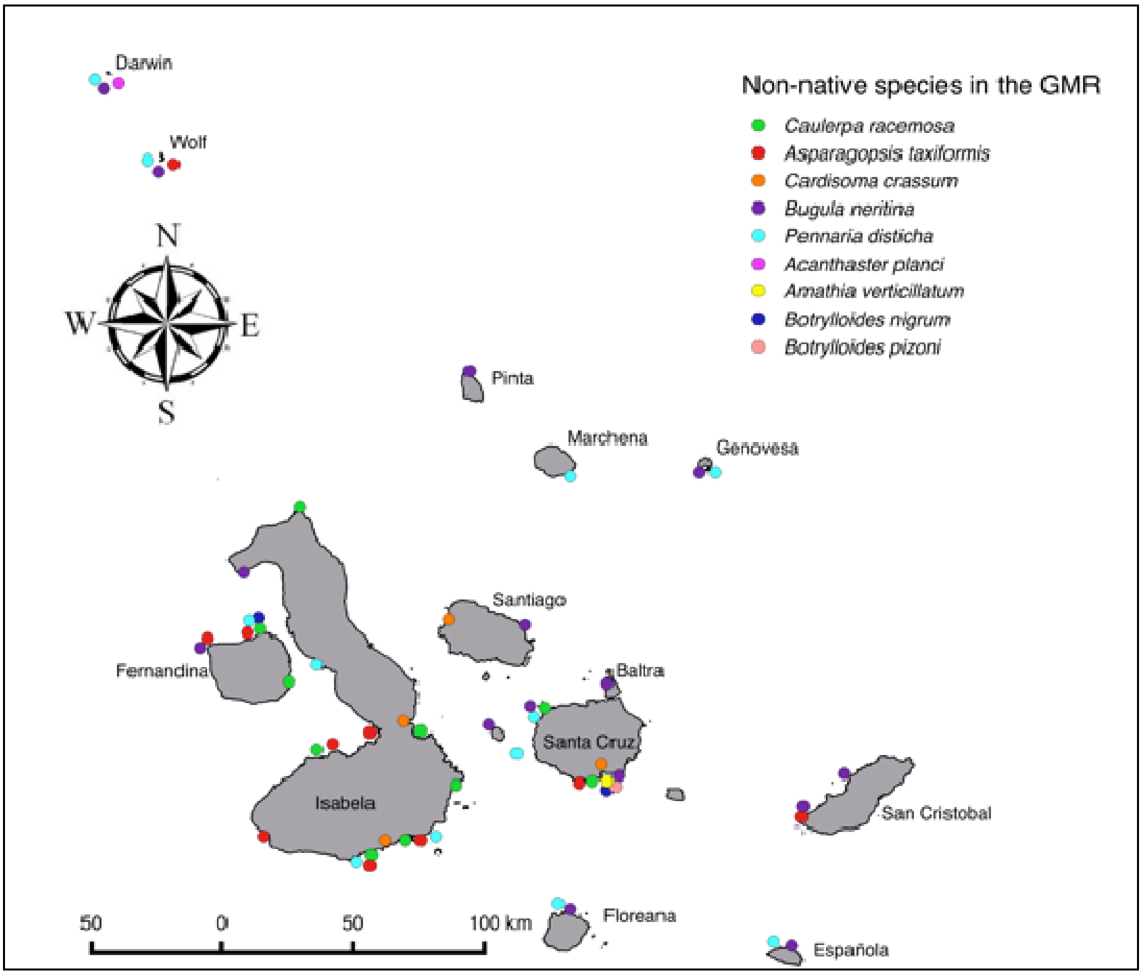


Figure 3.18: Distribution of non-native species in the GMR

3.6 Non-native species behaviour in the GMR

The historic records of *Caulerpa racemosa* discussed in chapter 2might influence people to think that this species is native due to the fact it has been present in the GMR for so long. CDRS has been running marine monitoring programs since 1997 (Bustamante *et al.* 2000; Danulat & Edgar, 2002) and there are records of *C. racemosa* that date back to the 1970's. In this research, it is suggested that *C.*

racemosa is non-native due to the more recent findings of this species being found in sites where it had never been reported previously and the observation that this species distribution can proliferate or contract due to water temperature changes, suggesting previous ENSO events could have influenced this species' presence and distribution.

During the surveys conducted in the protected bay areas around the archipelago, *Caulerpa racemosa* was found to be competing with native species. In Punta Albemarle on the northern point of the island of Isabela, *C. racemosa* was found to be competing with *Zoanthids cf. sansibaricus* (Figure 3.19) a common zoanthid found in subtropical and tropical waters of the Indian and the Pacific Oceans. In the Archipelago, this species is found in shallow, protected bays (Hickman, 2008).

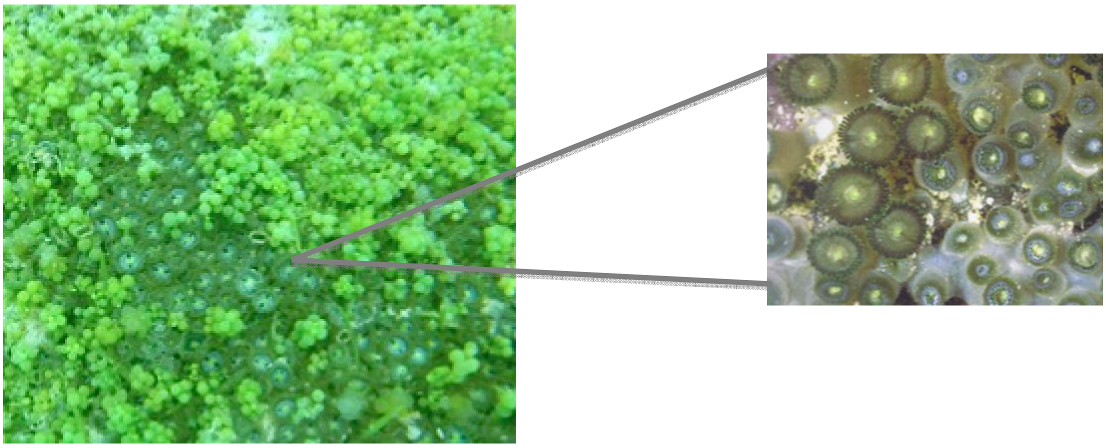


Figure 3.19: *Caulerpa racemosa* competing with *Zoanthis cf. sansibaricus, Punta Albermarle, Isabela Island.* ©Inti Keith.

On the north east side of the island of Fernandina at the site referred to as Punta Espinoza, large patches of *C. racemosa* were recorded, in this site, this species was seen competing with several species one of them being the anemone *Exaiptasia pulchella* formally known as *Aiptasia sp*. (Grajales & Rodriguez, 2014), (Figure 3.20). The benthic assemblage of the bays in Punta Espinoza have changed in composition several times in recent history (Wellington, 1975; Okey *et al.* 2003). Between 1998 and 2001 there where various reports of anemone barrens being present in the protected bays of Fernandina, whereas Wellington (1975) describes this area as a macro algal community consisting of *Ulva sp. Amphiroa sp*. and *Codium sp.* (Okey *et al.* 2003). This research presents yet again a different benthic assemblage including the established non-native green algae *C. racemosa.* The change in the species composition in these protected bays could be attributed to the climate variaility through ENSO events that the archipelago experiences.

Figure 3.20: *Caulerpa racemosa* competing with the anemone *Aiptasia sp.* at Punta Espinoza, Fernandina ©Inti Keith.

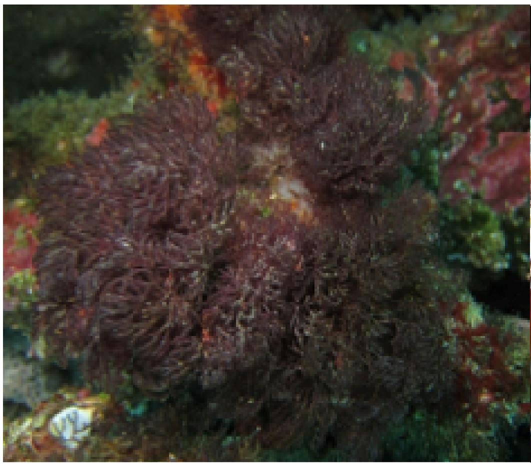
Similarly, *Asparagopsis taxiformis* historical records list this species as present since the 1960’s, but recent dive surveys have discovered new areas where this species was never recorded and has expanded rapidly, an example being the Marielas Islands off the island of Isabela (Figure 3.21a). This area was surveyed extensively between 1999 and 2002 to study the population density and fisheries impacts of the sea cucumber *Isostichopus fuscus,* during these surveys, *Aspargopsis taxiformis* was not recorded as present in the Mariela Islands (Priscilla Martinez, personal communication, 2015). The other site where *A. taxiformis* was found to be abundant was Cape Douglas (Figure 3.21b) on the northwest point of the island of Fernadina. The dive surveys conducted at this site recorded this species being present from +/- 3m to +/-25m. The sites where surveyed during different times of the year to see the effects of the temperature variation, the results showed this species thriving during the months where cold, nutrient rich waters flow towards the western part of the archipelago.

Figure 3.21:*Asparagopsis taxiformis* (a) Marielas Islands, Isabela, (b) Cape Douglas, Fernandina ©Inti Keith.

Cardisoma crassum also known as the blue crab has a segregated distribution in mangrove areas on central islands of the archipelago. During several searches conducted at night, *C. crassum* was found building burrows in the mud around the mangroves, which made this species hard to find (Figure 3.22). This species competes with native species for food and space, the biggest known population is in the mangroves near the town of Puerto Villamil on the island of Isabela and the locals often catch them for their own consumption.

Figure 3.22: *Cardisoma crassum,* Espumilla beach, Santiago Island

Bugula neritina and Pennaria disticha are the two species that have the widest distribution in the archipelago. *Bugula neritina* (Figure 3.23) was found in several of the docks in the populated islands as well as around the archipelago. This matches the hypothesis that this species was introduced to the islands by marine traffic and has spread. *Pennaria disticha* (Figure 3.24) is very common around the archipelago and can be found in all bioregions. These species compete for space with native and endemic species.



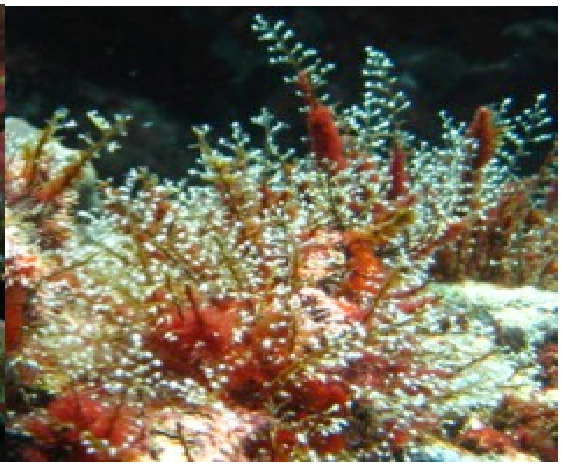


Figure 3.23: *Bugula neritina,* Bartolomé Island.**Figure 3.24:** *Pennaria disticha*, Bartolomé Island. ©Inti Keith

Acanthaster planci commonly known as the crown of thorns is found only on the island of Darwin in the far north of the archipelago (Figure 3.25). Only two individuals were observed during the dive surveys suggesting that the population of this species is small. This species is a well-known predator that feeds on corals, if this predator were to reduce the coral cover, other species could take advantage and use the areas for settlement and recruitment.

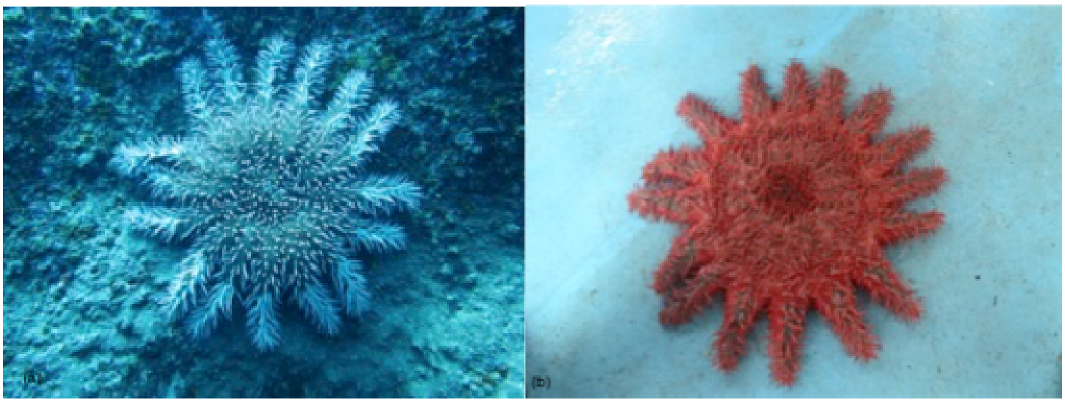


Figure 3.25: *Acanthaster planci* (a)in situ, Darwin Island (b) in the lab, CDRS ©Inti Keith.

The three new records *Amathia verticillatum*, *Botrylloides pizoni* and *Botrylloides nigrum* are all fouling organisms that could cause impacts to the docks and boats in the GMR, however as these species were found recently it is not clear how these species behave in the GMR at this time.

3.7 Discussion

Marine non-native species were identified in the GMR during this study. This is likely to grow as more research is conducted in this field and more molecular studies are conducted to positively identify species of ascidians and sponges that till now is an area that lacks research in the GMR.

The historical literature and recent dive surveys support the presence of these species, but it is difficult to demonstrate whether anthropogenic vectors resulted in the introduction of these species or if they arrived naturally. The research in this thesis suggests that these species could have arrived to the islands through marine traffic, current systems and climate variations. Six out of the nine non-native species are also found in continental Ecuador and in other regions in the ETP. *Acanthaster planci* has not yet been recorded in continental Ecuador, but has been recorded on the island of Cocos in Costa Rica, and in Panama (Keith *et al.* 2016).

Bugula neritina and *Amathia verticillatum* are both well-known fouling organisms that have been transported around the world for centuries, it is likely that these non-native species arrival resulted from marine traffic. The non-native species *Caulerpa racemosa, Asparagopsis taxiformis and Pennaria disticha* could have been transported by marine traffic as well as through natural dispersion. Whereas *Acanthaster planci* could have arrived at Darwin through oceanic currents or it could have migrated due to sea temperature changes during an ENSO event. This is thought to be the case as it was reported after the 1997-1998 El Niño event (Hickman, 1998). The crab *Cardisoma crassum* could have arrived naturally through trans-oceanic dispersal or, as Hickman (1997) proposes, was unintentionally introduced to the Galapagos Islands when some individuals were brought from continental Ecuador as food (Keith *et al.* 2016). Finally, the two species of ascidians *B. pizoni* and *B. nigrum* are fouling organisms, which suggests they arrived through by marine traffic.

Control and eradication methods within the national park are delicate subjects due to the vast amount of native and endemic species that exist in the GMR and the protection that these species have. However the management of marine invasive species is considered a priority for the Ecuadorian Government, the DPNG and ABG (Chapter 4). Different views exist when it comes to control and/or eradication of species, an interesting discussion was held during the first international workshop on marine bio-invasions of tropical island ecosystems held in CDRS (section 4.5). Some experts in this workshop suggested that *Acanthaster planci* should be removed immediately from the island of Darwin even though there has been no indication that this species is causing an impact on the coral reefs of this area of the archipelago (Chad Hewitt and Marnie Campbell personal communication, February 2015) the argument in removing this species is for prevention purposes in case there is a change in environmental conditions that allows this species to proliferate which in turn could cause a severe impact to the coral reefs. However, managers were hesitant to go ahead with this type of strategy due to the fact the arrival vector of this species is unclear and that there are no visible impacts to the marine ecosystem at this time.

The situation of *Caulerpa racemosa* and its expansion in some of the protected bays is an interesting case. It is clear that this algae overgrows native species as described in section 3.5 however it has been observed that the thermal variation that the GMR experiences throughout the year is a key variant in the expansion or reduction of this species. During the research for this thesis, a visual observation was made; during the months when cold water enters the archipelago this species abundance seems to reduce, giving native/endemic species a break from competition while during the hot season *C. racemosa*seems to expand causing an impact to the ecosystems. It can be suggested that the natural environmental conditions of the GMR act as a control for the over proliferation of this species, however, the risk arises when the normal environmental conditions are changed by climate variation such as ENSO events when temperature can increase +3 degrees. It is uncertain how *C. racemosa* and the other species might respond to climate change or climate variability. Currently, the GMR is experiencing climatic variations through a strong ENSO event that could not only change the behaviour of the mentioned non-native species, but the high water temperatures could cause mortality to some native/endemic species opening up niches for opportunistic invasive species to take over.

Looking at the management of these non-native species in the GMR is complicated as there is the argument from decision makers that if a species arrives for example through climate variability or oceanic currents (secondary dispersal), it is classed as a natural arrival, therefore, there is no need for management strategies. In contrast, any non-native that has arrived through an anthropogenic vector must have a management plan. This is understandable and coincides with several biological invasions terminology described in chapter 2. However as mentioned previously in this section it is very hard to know with any certainty the exact vector that transported these nine non-native species to the islands, therefore, in this thesis, it suggested that all non-native species must have a management plan in order to protect the marine ecosystems of the Galapagos Islands.

As part of the research for this thesis the results were presented to local stakeholders throughout the research (Keith *et al.* 2013; Keith & Martinez, 2014a; Keith & Toral, 2015) and several meetings with local decision makers (DPNG and ABG) where held to raise awareness of what species where present in the GMR and to discuss possible management strategies.

One of the concerns that the authorities from the DPNG had during the initial meetings was to know whether these non-native species had been introduced or if they had arrived naturally and if they where causing any impacts to the marine ecosystems in order to discuss management options.

Chapter 4:

Marine Traffic: an anthropogenic vector for the translocation of non-native marine species to the GMR

4.1Introduction

The isolation in which species in the Galapagos Islands have evolved makes them, even more vulnerable to compete with non-native species, and the continuous increase of marine traffic to the Galapagos Islands increases the risk of arrival of non-native species to this region. This chapter examines and discusses the different types of marine traffic that the Galapagos Islands receives and looks at the risks associated with this vector. Marine traffic is a prime example of an anthropogenic vector,shipping vessels can act as biological islands for species that live in harbours around the world (Wonham *et al.* 2001).As described in Chapter 3, the Galapagos Archipelago has received vessels from around the world since its discovery in 1535 and as tourism, trade and transport increase due to local and global growth the amount of marine traffic that enters the GMR has increased as well. Cargo ships, private yachts, research vessels, patrol boats and illegal fishing boats are the main examples of the types of vessels that enter the GMR on a weekly, monthly or yearly basis. To add to this, there is a large amount of marine traffic that navigates on a daily basis within the limits of the GMR.

4.2Marine traffic data

Marine traffic datasets for all vessels arriving to the Galapagos Islands from national and international ports have been obtained through the ABG, which is the agency responsible for conducting boat and hull inspections to all vessels that enter the main ports of the archipelago (ABG, 2015). The number of national and international arrivals for the period of January 2013 to April 2015 were analysed along with information of the last port of call that the vessels visited. Using this data a risk assessment was conducted, based on a similar study done in Australia (Hewitt *et al.* 2011). This risk assessment looks at the entry of international and national vessels into the GMR and the non-native species that could be transported by these vessels. In order to obtain a potential high-risk species list from around the world, the 18 IUCN bioregions and the global species distribution data was used (Kelleher *et al.* 1995; Hewitt *et al.* 2011). Following this, the impact that the arrival of non-native species could cause the environment, and the ecosystem services of the GMR was analysed. Datasets were obtained from the DPNG, the Ecuadorian Navy, the Ministry of Transport – *Ministerio de Transporte y Obras Publicas* (MTOP) and the Ministry of Tourism – *Ministerio del Ambiente del Ecuador*(MAE).

4.3National marine traffic traveling to the GMR

The marine traffic that travels between continental Ecuador and the archipelago comprises mainly of cargo ships. Other vessels that navigate back and forth from the archipelago are Ecuadorian navy patrol boats and research vessels from the Oceanographic Institute of the Ecuadorian Navy – *Instituto Oceanográfico de la Armada* (INOCAR), as well as tourist cruise boats that work in the Galapagos and undertake a dry docking on the mainland every two years, private yachts and illegal fishing boats.

Since 1970, there has been a steady increase in the number of residents that live permanently on the islands as well as a rise in the number of visitors. In 2010, the National Institute of Statistics and Census – *Instituto Nacional de Estadísticas y Censos* (INEC) conducted a population census in Galapagos, which produced the results of 25,123 people living on the islands (INEC, 2010). The DPNG produced figures in 2014 for visitors of 215,691 (DPNG, 2014a). The increase in population combined with the increase in tourism has put a demand on the amount of cargo that has to be shipped to the islands thereby increasing the number of ships needed. Between 2002 and 2006 four cargo ships travelled approximately 68 times a year (Cruz *et al.* 2007). By 2011, seven cargo ships transported goods to the islands, during this year a total of 224 trips were made (Bigue *et al.* 2013). In 2012 new requirements and regulations were put in place by the authorities and three ships were removed from operation leaving the cargo fleet with only four ships. During 2013, a total of 84 journeys were made to the islands, while in 2014 only 55 journeys were made due to several accidents (ABG, 2015). In January 2015, the Galapagos cargo operations were declared in emergency due to the fact that in a period of less than a year the archipelago had lost three cargo ships. Two had run aground in Wreck Bay on the island of San Cristobal and one ship sank leaving the Gulf of Guayaquil. After several months of the islands suffering a shortage of supplies. The Ecuadorian government through the Consejo de Gobierno del Régimen Especial de Galápagos (CGREG) delivered modern more efficient cargo ships between July and September 2015, with a third one arriving in October. These new cargo ships are much bigger in size and can transport more cargo using a containers system (CGREG, 2015a).

In the past, the loading of cargo took place in three docks in the port of Guayaquil, the facilities and services at these ports were minimum and did not comply with quarantine and biosecurity regulations that the MTOP and the CGREG wanted to implement for the cargo operations to the Galapagos Islands. In 2011, the old docks were closed down and Store Ocean was put into operation as the only dock that met the health conditions required for transporting cargo to the archipelago and also provided the facilities for quarantine and biosecurity procedures to take place (Bigue *et al.* 2013; CGREG, 2011). Store Ocean is a natural river port, located on the banks of the Rio Guayas (Figure 4.1), where the average water temperature recorded is of 26°C and a salinity of 8.2(Naranjo, 2002). The water is contaminated with high levels of solids and silicates, caused by the proximity to bulk storage tanks of fertilizer and cement. The surroundings consist of rocky benthonic habitats colonised by epiphytes and macro invertebrates (Suarez & Banks, 2013). Store Ocean is surrounded by several international shipping docks (Figure 4.2), whichreceive cargo ships from around the world that could transport non-native species to this area.

Figure 4.1: Location of Store Ocean – loading dock for cargo going to the Galapagos Islands**Figure 4.2:** Port of Guayaquil and the location of its main cargo docks

The old cargo ships would take three days to reach the island of San Cristobal, continue to Santa Cruz then Isabela and return to Guayaquil (Figure 4.3), with each ship taking around 21 days to complete the itinerary (Bigue *et al.* 2013). At the current time, there is still one cargo ship the MN Galapagos that conducts this itinerary. Two of the new cargo ships the MN Isla Bartolomé and the MN Fusion will complete the itinerary Guayaquil – Galapagos – Guayaquil in 14 days, which will allow for two trips per month. As mentioned previously, these boats are much bigger than previous used cargo ships; the MN Isla Bartolomé can transport 3,800 tonnes while the MN Fusion can transport 3000 tonnes. Due to the size of these ships, they do not navigate the same itinerary as the old cargo ships. These ships leave the port Store Ocean in Guayaquil and navigate directly to the northern coast of the island of Santa Cruz to the Itabaca Channel and the site Punta Carrion where there is deep water and a safe anchoring area. From here the containers are unloaded to barges and transferred to the islands of San Cristobal or Isabela or taken by land to the temporary collection centre on the premises of the CGREG in Puerto Ayora (CGREG, 2015a). The idea of this was to create a cargo hub whereby the cargo ships from the mainland enter and dock and then smaller vessels distribute the cargo between the islands minimizing the possible transmission of non-native species (Figure 4.3). However the MN Manizales that has a capacity for 7000 tonnes will be navigating to the islands of San Cristobal and Santa Cruz to deliver the cargo, from these islands smaller local vessels will be distributing the cargo to the islands of Isabela and Floreana (CGREG, 2015b).

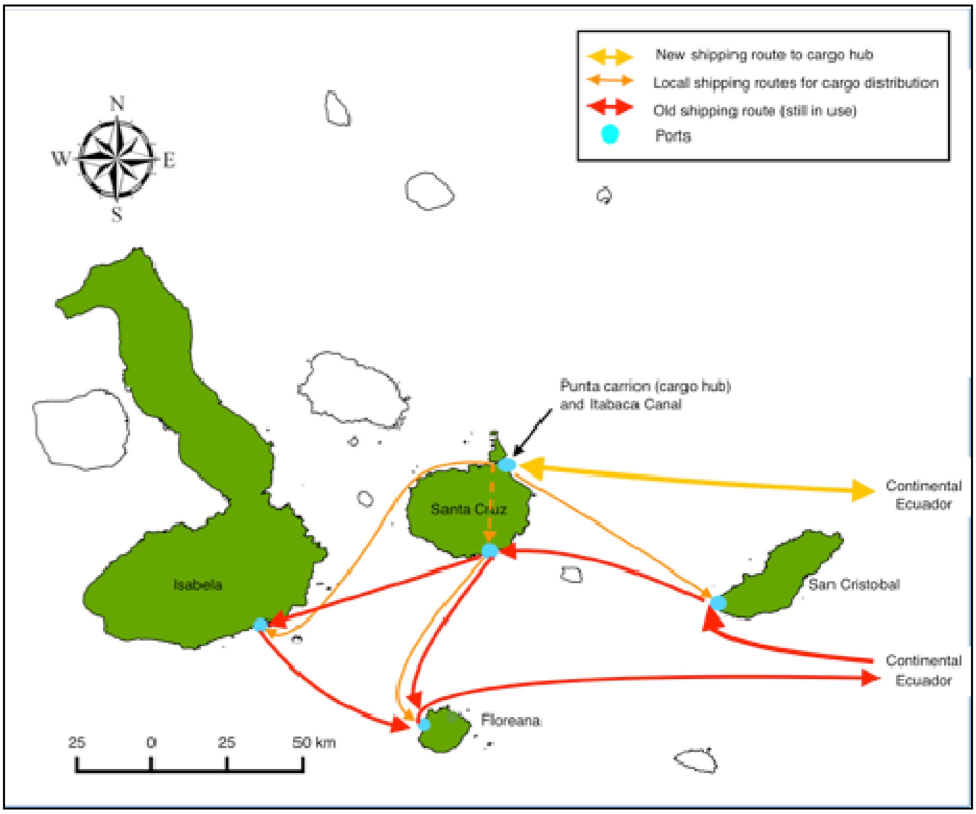


Figure 4.3: Shipping routes for cargo ships traveling to the GMR and within the GMR

Currently, cargo ships traveling to the archipelago do not take on ballast water, as they are loaded with cargo, and the brackish water of the Rio Guayas acts as a barrier for many species that cannot tolerate the change in salinity. It is important to stress that the risk for non-native species translocation can still exist as there are high-risk invasive species worldwide such as *Carcinus maenas* and *Mytilopsis sallei* that can support a wide range of salinity and high levels of pollution and succeed settling and proliferating.

Ecuador has other shipping ports that host several different types of national and international vessels; these ports are located down the coast of Ecuador and are connected directly to the Pacific Ocean (Table 4.1). The port of Manta is the largest seaport and the only deep-water port of Ecuador; it receives cargo ships, commercial fishing boats, artisanal fishing boats, private yachts and cruise ships. This port receives 67% of international cruises whilst the other 33% make their stop-over in Guayaquil and Esmeraldas. During 1997 five international cruise ships arrived to the port of Manta, since then there has been a steady increase in the number of cruises, with 33 ships recorded last season and 37 ships expected for the season of 2015-2016 (Ministerio de Turismo, 2015). Each company has a set itinerary that can vary between companies. Some examples of itineraries are: Fort Lauderdale, Florida/Cartagena, Colombia/Colon, Canal de Panama/Manta, Ecuador/Lima, Peru/Arica, Valparaíso, Chile (Celebrity Expeditions, 2015). Callao, Peru/Manta, Ecuador/ Puerto Limón, Costa Rica/Roatán, Honduras/Cozumel, Mexico/Miami, Orlando, New York, Boston, Bar Harbor, USA/Halifax, Canada/Islas Azores, Ponta Delgada, Funchai, Lisbon, Portugal (Oceania Cruises, 2015). San Diego, USA/Cabo San Lucas, Mazatlán, Huatulco, Puerto Chiapas, México/Manta, Ecuador/Callao, Peru (Holland America line, 2015). These examples illustrate how cruise ships that stopover in Manta have different routes, some come from the west coast of the USA, others from Peru and some ships navigate through the Panama Canal from the Caribbean or the Atlantic. These cruise ships can move species from one region to another on the hulls of the ships or in the ballast water, incrementing the risk for non-native marine species being introduced to the port of Manta.

Table 4.1: Marine ports on the coast of Ecuador and the type of boat that moor in each

Port	Puerto de Esmeraldas	Puerto de Bahía de Caráquez	Puerto de Manta	Puerto de la Libertad/ Salinas	Puerto Bolivar
Type of boat	• Cargo • Cruises • Fishing	• Private • Fishing	• Cargo • Fishing • Cruises • Private	• Oil • Fishing • Private	• Cargo • Fishing • Cruises

The GMR receives marine traffic from national vessels coming from mainland Ecuador and in some cases, international yachts make a stopover on the coast of Ecuador before travelling on to the Galapagos Islands (Figure 4.4). The other types of vessels that travel from these ports to the GMR are the fishing boats. Fishing in the GMR is only permitted for fishing vessels that are registered with the DPNG and follow the strict regulations that have been put in place. Fishing boats that travel from mainland Ecuador to the GMR to fish are conducting illegal activities, and this activity is punishable by law.

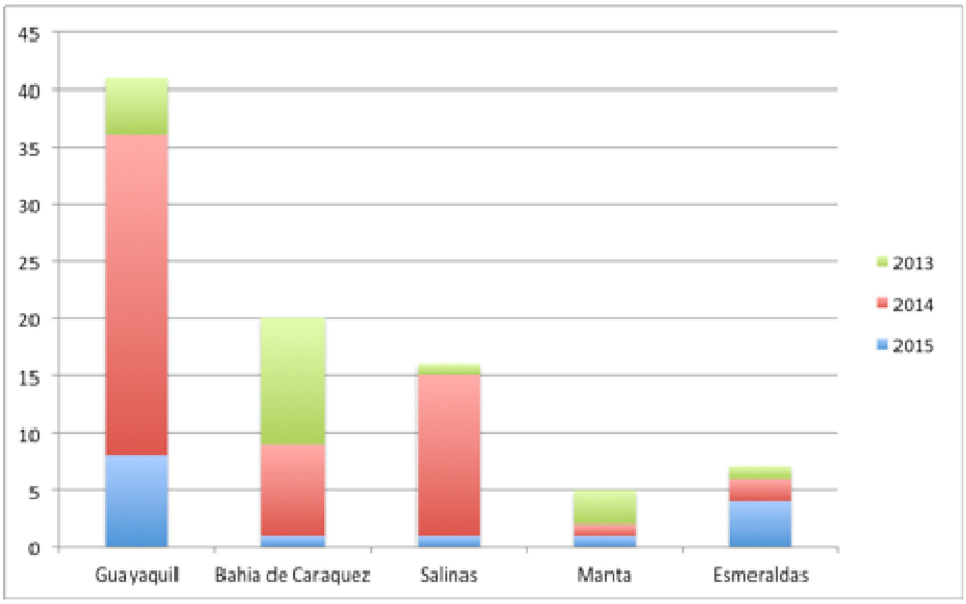


Figure 4.4: Number of yachts arriving to the GMR from continental Ecuador (2013-2015)

The fact that the ports mentioned in table 4.1 are connected directly to the sea and that they receive high numbers of international marine traffic increases the risk for a non-native species to be introduced and for these species to settle and colonise these ports. In the case that a non-native species were to colonise a port area, there would be a high risk that the species could be transported onwards to the GMR due to the marine traffic that travels to the archipelago from these ports.

4.4International marine traffic traveling to the GMR

The Galapagos Islands host thousands of visitors each year and the majority arrive by air, whilst others navigate oceans in order to reach the islands. The bulk of international marine traffic that the archipelago receives are private yachts and these can vary from small private yachts to expensive mega yachts. As recreational sailing and tourism increases around the world the ports of Galapagos have become an important stopover for yachts on passage as well as a tourist destination (Table 4.2). Private yachts enter the GMR on a yearly basis with the majority of them arriving between the months of December and June (Figure 4.5). These yachts arrive from all over the world with the majority reporting Panama as their last port of call (Figure 4.6 and 4.7).

Table 4.2: Number of international boat arrivals to the GMR between 2013-2015.

Year	Number of international boats	Data source
2013	253	ABG
2014	281	ABG
2015*	168	ABG

*Jan-April 2015 only, as data collection for this study stopped in April 2015.

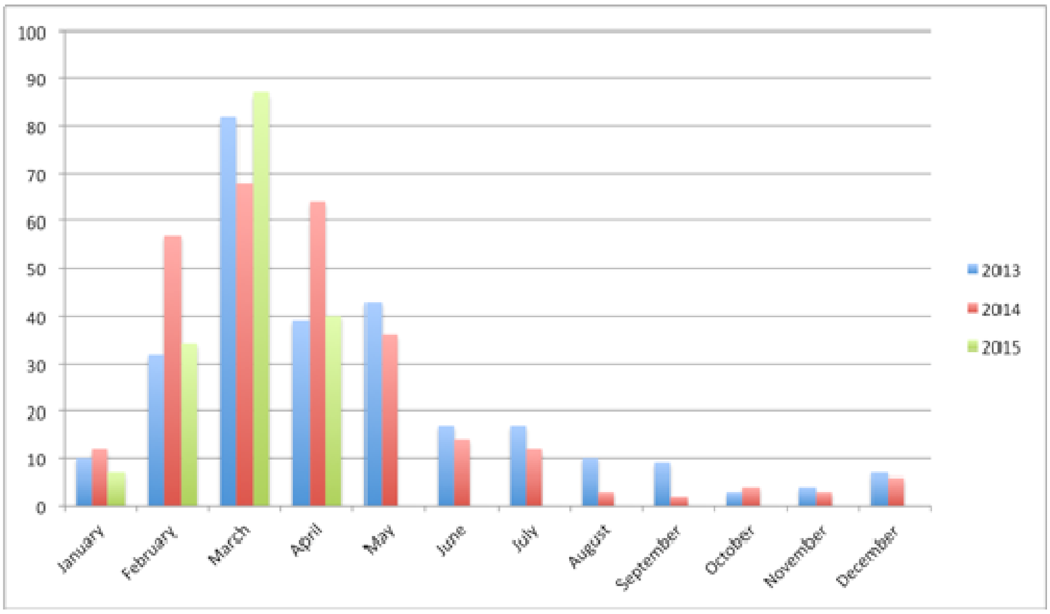


Figure 4.5: Number of international yacht arrivals per month

International vessels entering the GMR must navigate to one of the main ports in the archipelago, as it is not permitted to anchor anywhere but in an official port. On arrival, the local authorities including the ABG, DPNG, CGREG, Navy, MTOP, and the health ministry – *Ministerio de Salud Publica* (MSP) inspect all vessels. If a vessel is found to be transporting any kind of bio-incrusting species, the vessel is asked to leave the GMR in order to be cleaned and then return for a second inspection. Several regulations exist for how long an international or national vessel can remain in the GMR and where it can navigate within the archipelago.

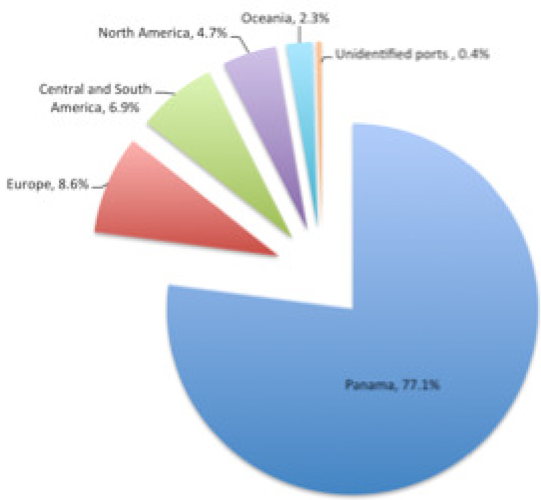


Figure 4.6: Geographic regions and their percentages, indicating the last port of call before sailing to the GMR.

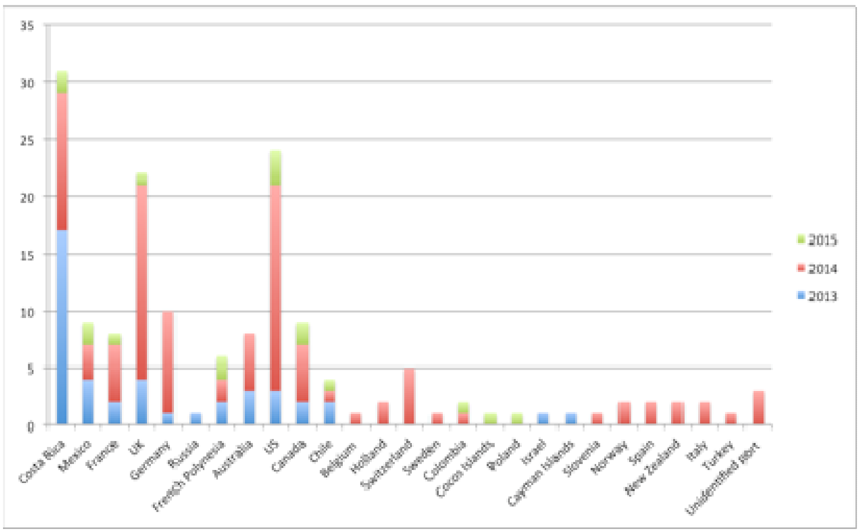


Figure 4.7: Number of international arrivals and their last port of call, excluding Panama (2013-2015)

Vessels arriving to the Galapagos Islands have the option of remaining in one port for a maximum of 20 days to refuel, buy supplies and visit tourist sites using local boats. This option does not allow for the vessel to move from the port of entry. Vessels wishing to remain in the archipelago for more than 20 days and/or visit more than their port of entry on their own boat must obtain a permit called an ‘Autografo’, this authorizes the vessel to visit the archipelago for up to 30 days with the possibility of a 30 day extension and it allows the vessel to visit the ports of Puerto Ayora, Puerto Baquerizo Moreno, Puerto Villamil, Puerto Velasco Ibarra and Puerto de Seymour. In the event of a problem, all vessels have the right to request a 72-hour emergency stop, be it for medical, mechanical or other issues. During this stop no refuelling or tourist activities are allowed, and the vessel must resolve the problem during this time or go through the normal arrival procedures.

International research vessels also visit the GMR to conduct scientific research, these vessels must comply with the regulations mentioned previously and in addition, these vessels must apply for a special permit awarded by the DPNG in order to conduct scientific research and be able to navigate around the GMR under a pre-arranged itinerary. Other boats that enter the GMR on occasions are the illegal fishing boats, with many of these boats coming from Costa Rica (Campbell & Hewitt, 2007).

4.5Local marine traffic in the GMR

Marine traffic in the GMR can be divided up into local, national and international vessels and then subdivided into the activities that each vessel conducts (Table 4.3).

Table 4.3: Categories of marine traffic in the GMR

Local	National	International
• Inter-island boats • Day tour boats • Cruise ships • Daily diving boats • Liveaboard dive boats • Artisanal tourist fishing • Research vessels • Fishing boats • Patrol boats • Private boats	• Cargo ships • Patrol boats • Research vessels • Private yachts • Illegal fishing boats	• Private yachts • Research vessels • Illegal fishing boats

The inter-island boats are speedboats that transport up to 30 people per boat between the populated islands of Santa Cruz, San Cristobal, Isabela and Floreana (Figure 6.8). These boats are regulated by the MTOP through the Subsecretaria de Puertos y Transporte Marítimo y Fluvial (SPTMF) and the Ecuadorian Navy. The number of boats travelling between the populated islands fluctuates significantly according to demand. During the first half of 2007, approximately 1,900 trips were made between the populated islands (Causton *et al.* 2008). However a study conducted in 2011 found that 8,726 trips where made between the islands (Bigue *et al.* 2013). Data collected from the ABG shows that during 2014 there were 12,854 journeys completed by the inter-island boats departing and arriving from the island of Santa Cruz (Figure 4.9).

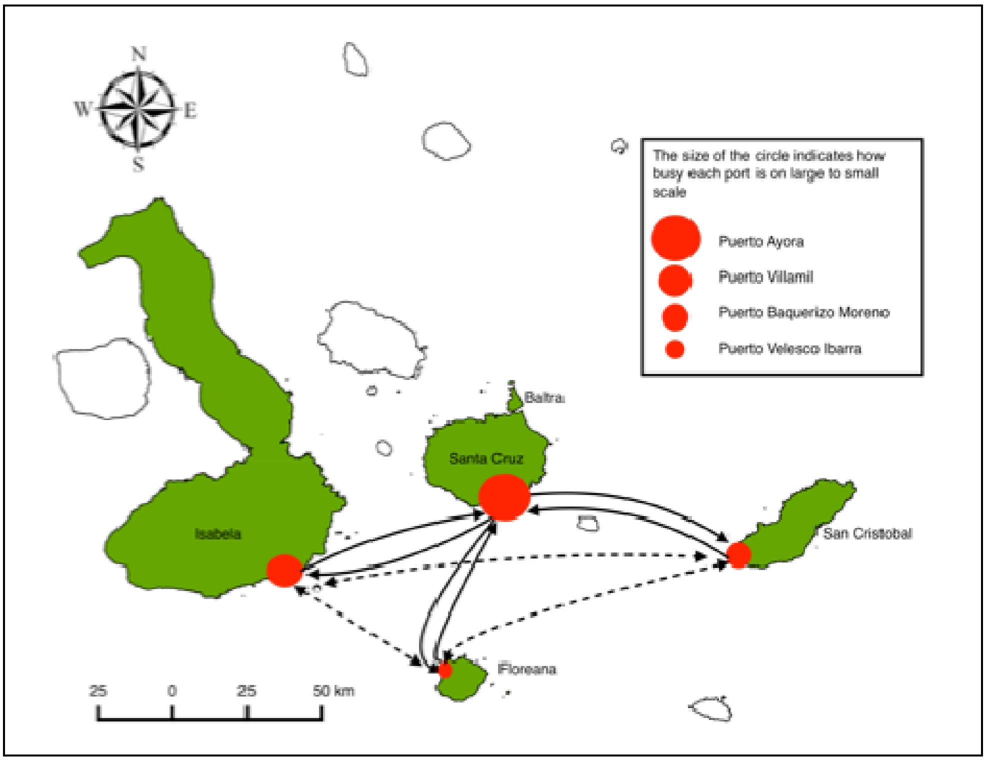


Figure 4.8: Map illustrating the inter-island traffic between the populated islands in the GMR. The solid black lines illustrate the most frequent routes whilst the dotted line illustrates the least common.

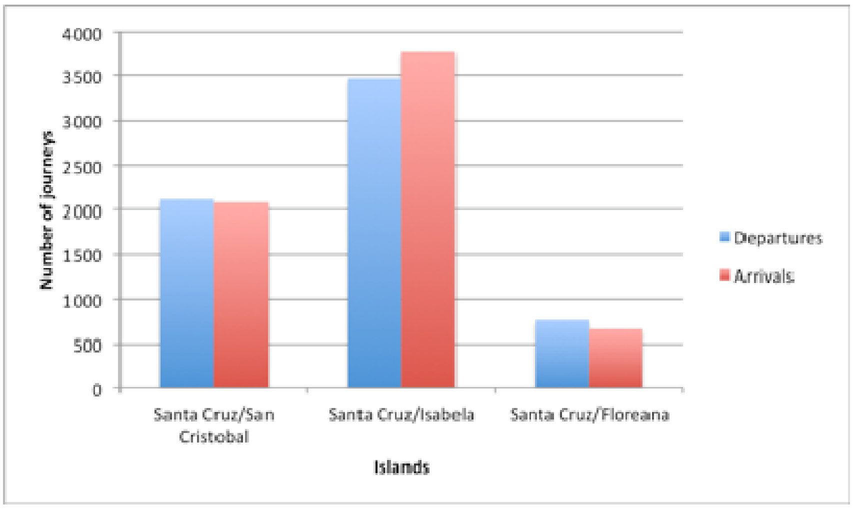


Figure 4.9: Number of journeys completed betweenthe populated islands by inter-island boats during 2014

Tourism is the main base of the Galapagos economy (Piu & Muñoz, 2008), where 61% of the tourists who visit do so from boats. There are 69 cruise ships that travel to the visitor sites using different itineraries created and managed by the DPNG. These itineraries are constructed in order to protect the environment and wildlife from the negative impacts that large groups of tourists can have on a visitor site. The possible impact on visitor sites is managed by looking at the "Groups at the Same Time" (GAMM) parameter of visitors. A group is defined as 16 visitors and 1 national park naturalist guide (DPNG, 2015a). Since 2012, the itineraries created by the DPNG distribute visitors to different sites with a 15-day frequency repetition. This allows all cruise ships to visit all the sites without overloading the site (Figure 4.10). Another way for tourists to visit the islands is by day tours that leave from Puerto Ayora or Canal de Itabaca (Santa Cruz), Puerto Baquerizo Moreno (San Cristobal), Puerto Villamil (Isabela) or Puerto Velasco Ibarra (Floreana). These tours go to visitor sites close to each main port and they can visit two sites per day. There are 10 day tour boats registered that can conduct this activity. Additionally, tourists can choose to do a bay tour on the 14 smaller boats registered for this activity.

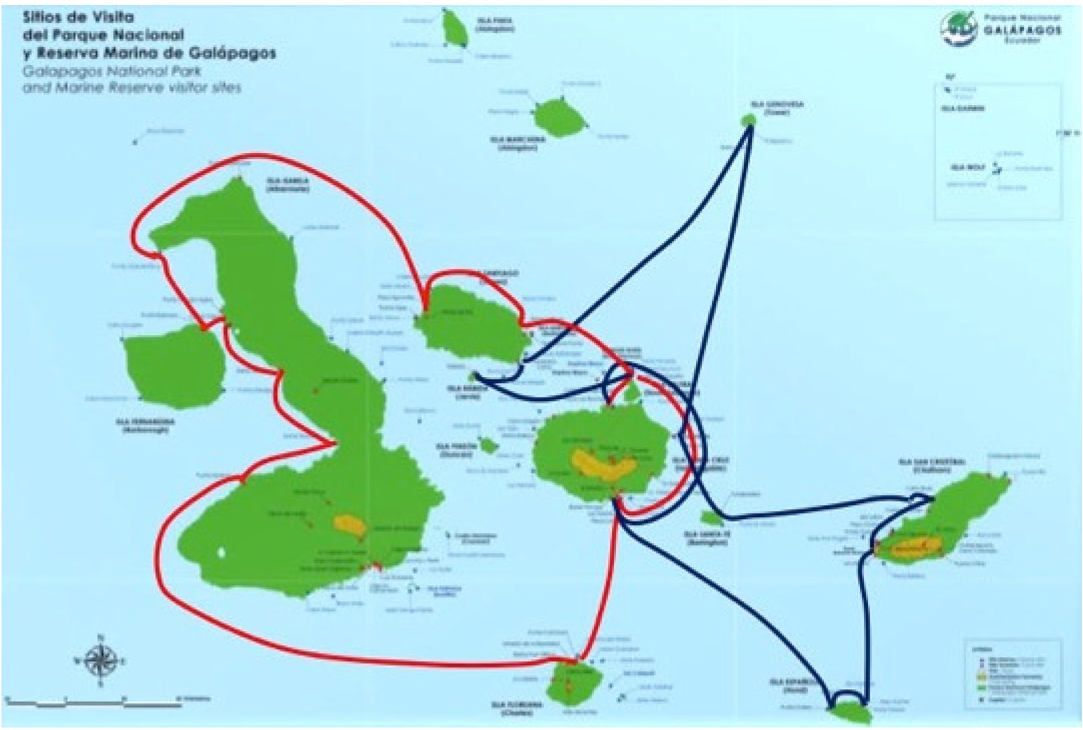


Figure 4.10: GNPD itinerary for cruise ships (©GNPD)

In the GMR there are two options for dive tourism. There are 23 daily dive tours that visit sites that are close to the main ports of each populated island and there are 5 liveaboard boats that visit the northern islands of Darwin and Wolf.Another type of marine tourism is artisanal fishing tours. This type of tourism is intended to show the tourist the techniques used by the artisanal fishermen as well as doing some snorkelling. There 37 fishing boats registered to conduct this activity. These boats have designated sites they visit which are different from the other tourist sites. The other marine traffic that navigates within the GMR are the fishing boats, private boats, scientific research vessels and patrol boats. These boats are more difficult to record since these do not have fixed itineraries or fixed routes.

This chapter has examined the marine traffic that enters the GMR from foreign and national destinations and discusses in detail the marine traffic that navigates within the GMR illustrating the increasing risk that the GMR is under when it comes to the possibility of non-native marine species being introduced by marine traffic. The chapter continues by analysing this risk and explores some risk assessment procedures for marine traffic.

4.6 Risk assessment for marine traffic arriving in the GMR and the consequences of introducing biofouling organisms

A risk can be defined as a situation involving exposure to danger, the possibility that something unpleasant or unwelcome will happen or something regarded as a threat or likely source of danger (Oxford Dictionaries, 2015). When talking about non-native marine species, it is definitions like these that are used to describe the risk of possible bioinvasions. A risk assessment is a process by which the likelihood that an event may occur is measured before the event takes place, and evaluating the consequences that the event could cause (Carlton, 2003; Campbell, 2009; Hewitt *et al.* 2009; Hewitt *et al.* 2011). The process requires identifying endpoints, identifying the risk, determining the likelihood of the event occurring, determining the consequences and calculating the risk (Campbell & Hewitt, 2008; Campbell, 2009). The identification of the risk endpoint is key to determine the direction the assessment will follow, whether it is (a) quarantine related or (b) impact driven (Campbell, 2009; Hewitt *et al.* 2009).

A key aspect in conducting a risk assessment is to identify what will be affected or impacted and what is at risk. A good way of assessing this is by applying core values that are important for the environment and community and that ensure those values are protected. These values can change depending on the place (context) and type of research to evaluate the values, and can have several subcomponents (Campbell, 2008). The idea behind these values is to use them to assess how the arrival of non-native species could affect both the environment (ecological effects) and the local community (social economic effects). It is possible to determine values by looking at ecosystem services and determining the value these services have for humans by connecting the ecological and the social systems (Vinueza *et al.* 2014). The marine ecosystem services that people benefit from most in the Galapagos Islands are based mainly on tourism and fishing as well as climate regulation and primary production. Therefore, the core values that could be impacted by the arrival of a non-native marine species in the GMR would be the following:

- The marine environment: impacts on the native/endemic flora and fauna, reduction or loss of biodiversity, reduction or loss of iconic species.
- Cultural: loss of aesthetic value due to invasion, loss of iconic species.
- Economic: decline in tourism due to invasion, costs from clean-up, elimination or decontamination procedures.
- Health: invasion causing issues to human health.

Marine traffic navigating to the GMR represents a primary route for the transport of marine non-native species. For the period between January 2013 and April 2015, a total of 698 international vessels arrived to the GMR, from 28 different destinations, whilst there were 240 vessels that made their arrival from continental Ecuador. In order to quantify the risk associated with this vector, a risk analysis was conductedto look at the international marine traffic arrivals and the high-risk species that could be associated with those arrivals.

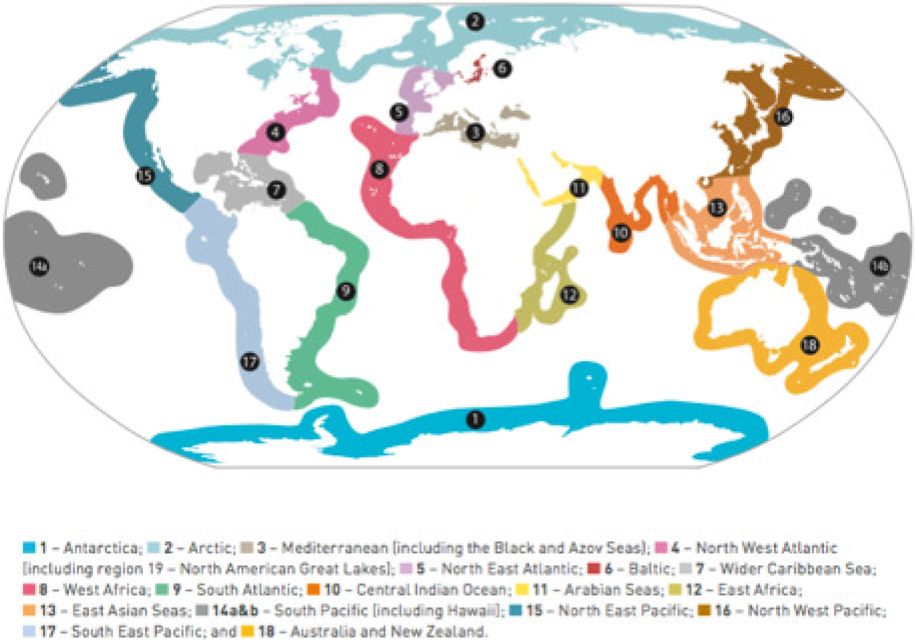


Figure 4. 11: IUCN bioregions as proposed by Kelleher *et al.* 1995, figure from Hewitt *et al.* 2011.

For this risk assessment, only international traffic was assessed as it poses a higher risk for the translocating of species from around world. The data analysed in this section is based on the 2013 international marine traffic data collected during this research and crossed with Hewitt and Campbell (2010) global dataset that lists 1807 non-indigenous marine and estuarine species (NIMES), Hewitt and Campbell (2010) obtained this information by conducting literature searches from over 700 data sources. The global species distribution data (NIMES) was then viewed within the 18 IUCN bioregions (Kelleher *et al.* 1995), which are considered to be a good representation of biological provenances(Figure 4.11) (Hewitt *et al.* 2011; Azmi *et al.* 2015).

4.6.1 Likelihood and consequences of a non-native species arrival

In order to be able to conduct a risk assessment, the likelihood of a non-native species arrival must be measured, and the impacts and consequences examined (Carlton, 2003; Hewitt *et al.* 2011). To measure the likelihood of the arrival of a non-native species, a likelihood matrix needs to be developed to measure the probability of the event taking place (Hewitt *et al.* 2011). The likelihood of non-native species arriving through marine traffic was identified earlier on in this chapter and the possible regions the marine traffic could be arriving from was identified (Figure 3.6). The following describes a likelihood matrix (Table 4.4) for the arrival of marine non-native species to the GMR based on work done previously in Australia (Hewitt *et al.* 2011).

Table 4.4: Likelihood matrix (Hewitt *et al.* 2011)

Likelihood	Description
Negligible (N)	Arrival is unlikely
Extremely Low (EL)	Arrival could occur with exceptional circumstances
Very Low (VL)	Arrival could occur, but is not expected
Low (L)	Arrival could occur
Medium (M)	Arrival is expected to occur in most circumstances
High (H)	Arrival is expected

This risk assessment looks specifically at the risk of biofouling organisms being transported on the hulls of vessels and does not take into consideration species that could be transported in ballast water. The reasoning behind this is that the majority, if not all international marine traffic that arrives to the GMR are vessels of a certain size that do not use ballast water. This risk assessment examines the likelihood of marine traffic from different bioregions arriving to the GMR and which biofouling organisms will be associated with that traffic. In order to measure the likelihood, a ranking system must be put in place to attain the consequences of the arrival of these biofouling organisms (Figure 4.12). The ranking system is based on the likelihood of a non-native species arriving and the consequences it can cause, figure 4.12 show colours similar to a traffic light illustrating green is low risk and red is high risk.

		Consequence					
		(N)	(EL)	(VL)	(L)	(M)	(H)
Likelihood	Negligible (N)	N	EL	EL	VL	VL	VL
	Extremely Low (EL)	EL	VL	CL	CL	L	L
	Very Low (VL)	EL	VL	VL	L	L	L
	Low (L)	VL	VL	L	L	M	M
	Medium (M)	VL	L	L	M	M	H
	High (H)	VL	L	L	M	H	H

Figure 4.12: Ranking system matrix for the arrival of non-native species to the GMR (modified from Campbell & Hewitt, 2008 and Hewitt *et al*. 2011)

A species-based exposure analysis was then used to calculate the likelihood of vessel exposure to species found on the NIMES list, which is then crossed with the 18 IUCN bioregions (Hewitt *et al.* 2011). The 2013 international marine traffic data presents a total of 253 vessels arriving to the GMR from 14 different regions worldwide. This information was inputted in the model to produce the vessels exposure to this list of species, which in turn generates a high-risk species list. The model constructed a list of 469 high-risk species (Appendix II). The high-risk species that was produced highlighted some interesting results, showing a number of species that are already present in the GMR. Two examples are *Pennaria disticha* and *Amathia verticillata*, with both these species having been recorded during this research and *A. verticillata* was reported for the first time in February 2015 (McCann *et al.* 2015). Both these species are common fouling organisms, and it is most likely these species were introduced to the GMR by marine traffic. This highlights that the exposure analysis model is a key tool in detecting which biofouling species could be introduced by marine traffic from one region to another.

4.6.2 Measuring the consequence of marine non-native species arrival

Measuring the consequence or impact of the arrival of a marine non-native species is key for decision makers all around the world in order for them to be able to mitigate the problem, however the impact of the majority of marine non-native species worldwide is unknown, with only a small percentage having been studied (Ojaveer *et al.* 2015). At the beginning of this section the importance of protecting essential values for the GMR were discussed (marine environment, cultural, economic, health) and it is these values that are impacted with the arrival of marine non-native species. Hewitt *et al.* (2011) developed consequence matrices that are associated with core values and are ranked for biosecurity purposes in order to determine the impact that the arrival of a marine non-native species could cause (Ojaveer *et al.* 2015). These consequence matrices were developed for marine non-native species introduced in New Zealand (Campbell, 2008; Hewitt *et al.* 2011).

These consequence matrices were adopted for use in this research to try to measure the impact of the arrival of the high-risk species identified from the species-based exposure model. The table in (Appendix II) illustrates how the 469 species have a high likelihood to have been exposed to vessels travelling to the GMR. Many of these are well-known species that have been introduced to different regions and have caused major impacts (e.g. *Mytilopsis sallei, Perna viridis, Membraniporopsis tubigerum* or *Megabalanus coccopoma),* (WoRMS, 2015b). Other species on the list are less well known, and their impacts have not been studied which is the case with many marine non-native species worldwide. This situation, in many cases, has led decision makers to believe these species cause little or no impact, which, until research has been conducted, is erroneous leading to potentially flawed management decision (Ojaveer *et al.* 2015). When looking at the consequence matrices (Appendix III) and the designated core values for the GMR it is clear that, due to the importance of the GMR as a world heritage site and the high percentage of endemic animals, the arrival of any non-native species that potentially threatens the habitat, biodiversity or ecosystems should be ranked as a species of high risk. Likewise the social/human dimensions to the GMR rely on tourism and fishing for a living, which is why if the arrival of a marine non-native species can threaten the national importance of the islands, the iconic species and places, the appearance of visiting sites, the economy or health. It is clear that these species should be ranked as high-risk. This conclusion supports the theory of considering all non-native species that could arrive to the GMR as high risk in order to protect the very important environmental and social values that exist in this region.

4.7Discussion

This chapter has reviewed the marine traffic that arrives to the islands - from international destinations on a yearly basis (surveyed on a yearly basis), to the national vessels and the marine traffic within the archipelago. This vector is thought to be the most important anthropogenic vector for the transport of marine non-native species to the GMR. The data shows how a large percentage of marine traffic that arrives to the GMR comes from different regions especially from Central

America and Panama specifically. However it is not only marine traffic coming from international ports that the archipelago has to be concerned with, it is also the national and/or international traffic that leaves from the ports on the coast of continental Ecuador, as these ports attract marine traffic from around the world and can act as a hub for the translocation of non-native species. Vessels visiting these ports before arriving to the GMR could pick up unwanted 'hitchhikers' and transport them to the GMR. This research suggests that even though it is true that a large amount of vessels come from Panama due to the Panama Canal connection, it is thought that the lack of information obtained from the arriving vessels about the last port of call could be misrepresenting the amount of regions that need to be considered for a risk assessment. It is suggested that the ABG should modify the inspection forms to contain a clear question of where the vessel originated from and a separate question relating to where the vessel originated from and the last ports visited prior to the arrival to the GMR. Having more information about where the vessels have been allows a more in depth risk analysis that can give more concise results.

The risk of species being transported from continental Ecuador by cargo ships was explored and the improvements to both the vessels themselves and the quarantine ports were discussed showing an increasing interest by the Ecuadorian government in increasing biosecurity for the GMR. There is a large interest in consolidating this idea of having cargo hubs and organisations like WildAid are working with the Ecuadorian government to try to fulfil all the requirements necessary for a good quarantine and biosecurity management system for the Galapagos Islands both terrestrial and marine. Having a cargo hub in the GMR will minimize the risk of potential high-risk species being transported to all ports within the GMR.

The risk of species dispersion within the islands is high due to the large amount of different tourist boats and sites that exist within the GMR as well as the inter-island boats, patrol and fishing vessels. The management plan the DPNG has in operation to control the number of tourist at one site was explained, however this plan only looks at the carrying capacity of the island and the tourist site. It is suggested that further research should be conducted looking at the frequencies of travel between sites by the different types of marine traffic in the GMR. This information could be related to the distribution of the marine non-native species present in the GMR at this time to look at dispersion patterns within the archipelago. Campbell *et al.* (2013) introduced the idea of conducting a hub and spoke network model to analyse the secondary dispersal within the Galapagos Islands (Azmi *et al.* 2015).

Using data collected for this thesis, a species-based exposure analyses illustrated the high risk that marine traffic poses on the GMR.In this thesis, it is suggested that due to the importance of the GMR and in order to protect the core values discussed for the GMR in section 4.6, all non-native species should be considered of high-risk until proven otherwise in order for managers to be able to enforce strict management plans.

An efficient policy to support conservation and social sustainability must act on the connections between Galapagos, continental Ecuador, and the rest of the world, to reduce the flows of non-native species that enter (and leave) the archipelago (Grenier, 2010).The management of incoming vessels and adequate quarantine protocols need to be put in place. The ABG and the DPNG have commenced hull inspections to all boats entering the GMR, which is a starting point for the control of non-native species entering the GMR. However, more work has to be done to prevent species arriving. The inspection protocols have to be extended beyond the GMR, to the last port of call or beyond, all boats should arrive to the Galapagos with clean hulls and be re-inspected upon arrival (Keith *et al.* 2016).

One of the biggest challenges that managers of the GMR encounter is how to enforce extreme quarantine and inspection protocols without affecting the local community and tourism, which is the archipelagos main source of income. The species-based exposure analysis illustrated how many non-native species could have potentially arrived on the hulls of the boats that entered the GMR and how all of these species could cause an impact on the core values that are important for the Galapagos Islands. This thesis suggests that in order to improve the biosecurity for incoming marine traffic the marine quarantine controls have to be expanded beyond the GMR. All marine traffic entering the GMR should be inspected in the last port of call before arriving to the GMR and the inspections carried out by the ABG, and the DPNG should be a re-inspection. At this time, ABG officials ask international vessels on arrival for proof of the vessels hull being cleaned in the last port of call. The ideal management strategy suggested in this thesis is to form a network of biosecurity agencies throughout the ETP region and beyond that work reciprocally in order to prevent the spread of marine non-native species. Additionally, quarantine areas separate from all other vessels in the marine ports should be designated in order to carry out inspections. This way the quarantine area can be monitored constantly for non-native species arrivals and the arriving boats have no contact with local boats that navigate within the GMR. At this time, if a vessel arrives and does not pass the hull inspection, the authorities ask the vessel to leave the GMR at their own cost and clean the hull before returning for re-inspection. This policy is not very friendly towards tourism, and it can be dangerous to clean a hull in the middle of the Pacific Ocean even though it is understandable that authorities are trying to minimize the risk of non-native species arrival.

There are several options that could be enforced by local authorities; however, many of these solutions would need a strong investment. A possible solution would be to build a multi-purpose hull cleaning dry dock area in conjunction with the cargo hub the Ecuadorian government and WildAid are discussing building. This area would require a freshwater system and the drainage system would have to be closed off to the sea to ensure nothing was deposited into the sea. Another option would require investing in purpose built plastic canvases that surround the vessel prior to cleaning it. This method consists of using fresh water and scraping the organisms from the hull. The idea of the canvas is that all debris remains in the sealed canvas in order to dispose of the debris safely after cleaning. Whatever the method of choice, the important factor to consider is the implementation of heavy fines to all vessels that arrive with dirty hulls. An outreach program would need to be set up informing boat owners of the fines that will be applied to vessels with dirty hulls.

At this time cargo boats that arrive to the GMR do not get inspected due to safety considerations and logistics interfering with the offloading of cargo. This thesis suggests an alternative management plan specifically for cargo ships. The Ecuadorian government would need to invest in a hull-cleaning machine that would work on cleaning the hulls of the cargo boats while they are docked loading cargo in the port of Guayaquil. In this way the cargo boats are cleaned regularly minimizing the risk of transporting non-native species to the GMR and avoiding any safety or logistical issues.

The management of marine traffic to the GMR and within the GMR has been illustrated in this chapter as a clear necessity for the prevention of marine non-native species arriving to the GMR. It is positive that the Ecuadorian government and the local institutions in the GMR are working towards improving the biosecurity in order to prevent a possible invasion however stricter protocols need to be in place and enforced not only in the GMR but also in the region as a whole to ensure the protection of the marine ecosystems of the GMR. The following chapter describes the risks associated with natural vectors as well as a discussionnatural processes that are influenced by anthropogenic activity and the management considerations that can be applied to these.

Chapter 5:

Natural Vectors – Secondary spread

5.1Introduction

A synthesis of the marine traffic in the GMR was described in Chapter 4, suggesting that this anthropogenic vector could be the most influential vector in the transport of marinenon-native species to the GMR. This chapter discusses how marine non-native species can also be transported through natural dispersion or geographical range expansion from one region to another and illustrates the different types of natural vectors that influence the archipelago. This chapter additionally examines natural processes that are influenced by anthropogenic activity such as climate change and marine debris and looks at how these should be categorized. An example of how species can be transported on debris is the case of the charismatic (an now endemic) species the marine iguana which is likely to have come about by the terrestrial (green) iguana from continental Ecuador being carried by floating 'vegetation rafts' and subsequent adaptation over thousands of years. Furthermore, species distribution modelling is examined in this chapter to illustrate the predicted habitat suitability of 19 potential non-natives that are a danger for the GMR. The risks of these species arriving to the GMR through range expansion are discussed.

The GMR is part of the ETP a region that exhibits a high level of natural connectivity and is influenced by a number of major surface and submarine current systems. The cold and warm tropical systems provide unique habitats in the GMR. The archipelago also experiences a huge amount of climate variability caused by ENSO events that cause an increase in water temperature, increased precipitation and changes in current circulations. Marine non-native species can benefit from these natural occurrences and can be dispersed to a new region where they can establish and spread.

5.2Natural dispersion vectors for transport of non-native species to the GMR

5.2.1 Connectivity within the ETP – oceanic current dispersal

The ETP extends from southern Mexico to northern Peru and includes several islands and groups of islands including the Galapagos archipelago. It is considered one of the most productive tropical oceans of the world (Spalding *et al.* 2007). Within the ETP there are several oceanic islands that form part of large Marine Protected Areas (MPA's) in the region, examples being the GMR, the Cocos Island National Park, the Malpelo Flora and Fauna Sanctuary and the Coiba National Park. The islands, coasts and waters between these MPA's cover an area of nearly two million square kilometres, which is often referred to as the Eastern Tropical Pacific Seascape (ETPS) (Bessudo *et al.* 2011).

The biophysical environment of the ETP is very unique; the confluence of warm and cold currents allows for unique biological communities to exist in this region (Kessler, 2006; Fiedler & Talley, 2006). The region is characterised for having different water masses, current systems, high levels of productivity, diversity of ecosystems and natural connectivity due to the convergence of major currents.

The GMR is in the centre of this convergence of currents and is influenced by four distinctive currents throughout the year (Figure 5.1). The Panama Current brings warm water from Central America whilst the Peru Oceanic Current brings cold water from Chile and Peru whereas the South Equatorial Current is a cool surface current that flows westward towards the islands. This latter current changes its intensity depending on the interactions of the previously mentioned currents and the time of the year. The Equatorial Undercurrent brings deep, cold, nutrient rich water to the west of the archipelago (Muromtsev, 1963; Banks, 2002; Hickman, 2009).

Figure 5.1: The ETP region illustrating the oceanic currents that influence the GMR, modified from the Conservation InternationalETPS map.

Oceanic currents heavily influence oceanic dispersal. These currents make it possible for species to be dispersed between widely separated areas, especially species capable of long distance larval transport (Hickman, 2009). For most marine organisms with sessile, benthic or sedentary adult phases, movement is often limited to their larval phase and dispersal. However, these early life history stages are never entirely passive and represent a unique opportunity for individuals to be transported between geographically separated populations using oceanic currents (Paris *et al*. 2013; Pineda *et al.* 2007).

5.2.2 Climate variability and ENSO events

The ocean is well known to play a dominant role in the climate system because it can initiate and amplify climate change on many different time scales. The best known examples are the inter annual variability of ENSO – El Niñoevents and the potential modification of the major patterns for oceanic heat transport as a result of. greenhouse gases (Semtner, 1995). The Galapagos Islands are regularly subjected to extreme climate variability through ENSOevents. These strong climatic events cause increases in temperature, changes in current circulation and changes in precipitation. During 1982-1983 and 1997-1998 two strong El Niño events were marked with widespread damage caused to the marine ecosystem of the Galapagos Islands, largely due to trophic cascades and food shortages. During

ENSO events, prolonged increases in sea temperature are induced as the warm surface waters of the western Pacific band migrate to the coast of South America (Banks, 2002). During such events when extreme conditions occur, the geographic range of some warm water species can expand, moving them to different regions (Keith *et al.* 2015).

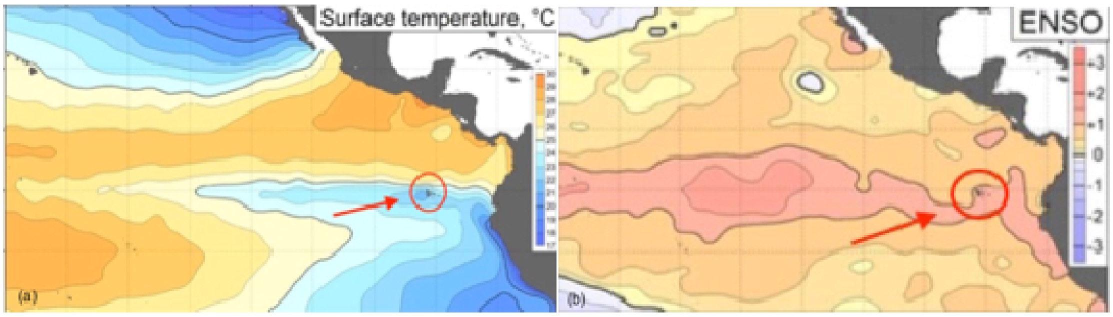


Figure 5.2: (a)average sea surface temperatures in the ETP. (b) sea surface temperatures in the ETP during and ENSO event. (The arrow indicates the GMR) (Modified from Fiedler & Talley, 2006)

The sea surface temperatures (SST) in the GMR can rise +3°C above the mean SST during strong ENSO events (Figure 5.2) giving opportunistic thermally tolerant species a window of opportunity to migrate with the warmer water to a region that would normally be limited to a temperature barrier. During an ENSO event with temperature patterns like those in Figure 5.2b non-native species could migrate from the regions of Costa Rica, Panama, Colombia, continental Ecuador and the north of Peru. Although these conditions may be favourable for some species, there are several species in the GMR that do not withstand severe climate variations. In the case of fish and mobile macroinvertebrates these can migrate to colder waters in order to survive, but in the case of sessile organisms and algae these species remain throughout the extreme climatic event and often do not survive. Both these situations can create a niche available for an opportunistic species from a different region to enter, transforming the marine habitat. The question is whether the new invader will manage to survive after the conditions return to normal? (Figure 5.2a) There are two possibilities i) the non-native species establishes, reproduces, potentially spreads and adapts to the conditions or ii) the non-native species cannot survive the normal conditions of the GMR and fails to establish. The problem with the second option is that this still leaves an open niche where another non-native could enter and invade and the cycle repeats.

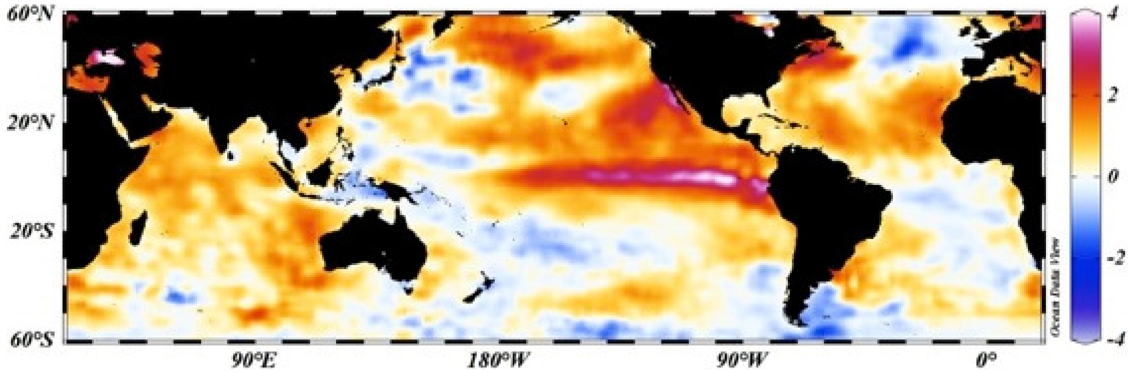


Figure 5.3: Sea surface temperature anomaly in the ETP October 2015(NOAA NCEP EMC CMB GLOBAL *Reyn_SmithOIv2,* Processed: CIIFEN, 2015)

5.3 Secondary spread enhanced by anthropogenic activity

5.3.1 Climate change

Global climate change is expected to warm the earth's surface and increase air and water temperatures, causing effects on ecosystem services (Rahel, 2002; Hare & Whitfield, 2003). When a habitat has been changed, for example, through climate change, invasive species can use the disturbed environment to establish and spread a lot easier than if the system was stable and could resist the invasion (Emerton & Howard, 2008). Biodiversity is being affected by climate change with changing temperature and rainfall patterns (Dawson *et al.* 2011). Some native species struggle to adapt to new conditions, yet invasive species, being generalists, can more easily adapt, establish and spread (Emerton & Howard, 2008). There are cases recorded where long term changes in ocean temperatures have influenced the distribution of fish species in their native range (Hare & Whitfield, 2003; Perry *et al.* 2005). How non-native marine species are reacting to these changes is yet to be fully examined or understood (Hewitt &Campbell, 2013). The change in global climate could affect the ecosystems in the GMR, allowing marine non-natives to take advantage and proliferate.

5.3.2 Marine debris

Oceanic currents can also transport marine debris that can have species attached. Examples of these include lost fishing nets and abandoned fish aggregating devices

(FADs). These can potentially harbour invasive species and can be carried by currents to different locations (Hilliard, 2004). The marine debris provides another example of a potential vector for introduced species (Vegter *et al.* 2014); a point in case is the Japanese tsunami in 2011. A year after the devastating earthquake and tsunami, a floating dock appeared on the coast of Oregon in the United States with several invasive species attached to it, some examples were: *Undaria pinnatifida* ("wakame") also known as Asian kelp, *Hemigraspus sanguineus,* commonly known as the Japanese shore crab, and *Asterias amurensis,* known as the Northern Pacific seastar (Chan, 2012). This demonstrates how invasive species can be transported across a large body of water by currents and winds attached to floating debris. Marine debris is human created waste that enters a natural environment where natural processes, such as ocean currents, spread the debris.

5.3.3Aquaculture on the coast of Ecuador - a risk for the GMR

In April this year, three aquaculture sea cages were installed in the province of Manabi on the coast of Ecuador in order to farm *Rachycentron canadum* commonly known as cobia. This species does not occur naturally in Ecuador. *Rachycentron canadum* has high potential in marine aquaculture because of its high growth rate and adaptation to the aquaculture environment. The Ecuadorian government granted the first marine area concession and awarded an area of 86.70 hectares for the development of aquaculture, through the implementation of the project "Marine research for the farming of cobia" (*Rachycentron canadum)*.

Reports of cobia escaping from the cages were reported in the media during August and September this year, with local artisanal fishermen reporting they were catching*Rachycentron canadum*in their nets (Fenacopec, 2015; El Universo, 2015). Experts from the MAE, the Subsecretaria de Gestion Marina y Costera and the DPNG inspected local artisanal fishing landings and confirmed the presence of this species. Additionally the cages were inspected and the findings suggested that deterioration of the cages and poor maintenance were responsible for the fish escaping (MAE, 2015a).

Cobia has a worldwide tropical and subtropical distribution, but wasabsent in the eastern Pacific and the Pacific Plate (Figure 5.4). It is present in the Western Atlantic from Argentina to Canada including the USA, the Gulf of Mexico and the Caribbean. In the Eastern Atlantic it is present from Morocco to South Africa. In the Indo-West Pacific it is present in East Africa and Hokkaido and from Japan to Australia (Froese & Pauly, 2015).

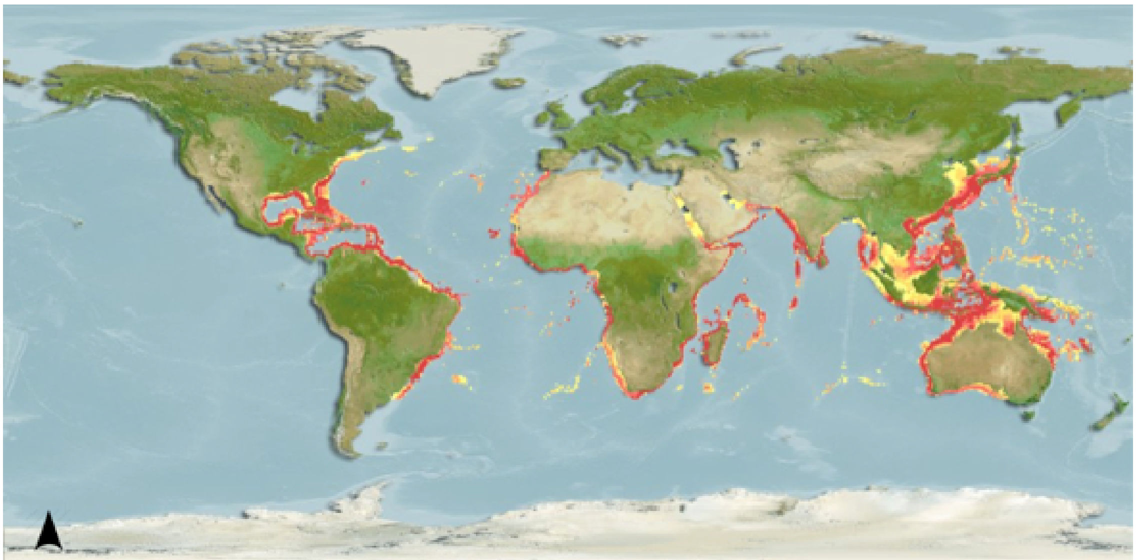


Figure 5.4: Native distribution of *Rachycentron canadum* (FishBase, 2015)

The risk of this species reaching the GMR is high as this is a pelagic species that could expand its range from the Ecuadorian coast to the GMR and the rest of the region with ease. This species can tolerate wide variations in temperature (16.8°C - 32.2°C) and salinity (22.5ppm - 44.5ppm) (Kaiser & Holt, 2007; Shaffer & Nakamura, 1989). Sexual maturity of *Rachycentron canadum*is reported in males between 1 and 2 years and with a size of about 52cm in length and in females between 2 and 3 years with a size of about 70cm. Spawning can occur both in coastal waters and offshore, the females can release hundreds of thousands to several million eggs that are then fertilized by the males. The larvae grow rapidly and are large in size in comparison to most marine species. This species is known to congregate in reefs, shipwrecks, ports, buoys and other structures, they may also enter mangroves in search of prey. Cobia is a high trophic level carnivore that feeds on crustaceans, cephalopods and small fish (Kaiser & Holt, 2007; Shaffer & Nakamura, 1989).

The climate variability that the GMR is experiencing at this time due to ENSO events could benefit this species range expansion. Cobia could cause several adverse effects to the marine ecosystem in the GMR. As a potential predator this species could reduce the populations of shellfish and fish of the GMR and compete with other species causing alterations in the natural habitat. In addition, Cobias are susceptible to viruses, bacteria and parasites that commonly afflict other warm water marine species, if this species was to enter the GMR it could also introduce diseases.

The arrival of this species to the GMR would be considered a natural arrival, however if this species was to expand its range and arrive to the GMR or elsewhere in the region it would be due to the intentional introduction of this species to the coast of Ecuador for aquaculture purposes and posteriorly the accidental introduction to the marine environment due to individuals escaping. It can be argued that anthropogenic activity was the primary cause for this species being introduced to the region and the subsequent natural dispersion is a consequence from the introduction. Therefore, with regard to the introduction of non-native species to the marine environment, the combined effect of anthropogenic introductions with potential long-range natural dispersal to wider regions should be a consideration when making management decisions on biosecurity issues.

5.4 Species Distribution Models: modelling invasion risk of non-native species reaching the GMR

Species distribution modelling (alternatively known as 'bioclimatic envelop' or 'environmental niche' modelling) can help predict where a species distribution can potentially expand to geographically by using global environmental data. A Species Distribution Model (SDM) uses algorithms and models combined with distribution and geographical data in order to predict distributions. These models are not only important in the present day research of species distribution but they can also be used to predict future species range expansion by inputting future climatic predictions and projecting the suitable areas for a certain species to expand to.

In this section public domain environmental and occurrence data was used and entered into modelling software in order to look at the expansion range of non-native species and the likelihood of these species reaching the GMR. The MaxEnt program for maximum entropy modelling of species geographic distribution version 3.3.3k(MaxEnt, 2015)was used. This model is based upon presence only species occurrence data to predict environmental suitability based on the relationship between the training occurrence data and the environmental data, and has been shown to work well, even when few species occurrence data is available (Phillips *et al.* 2006; Phillips & Dudik, 2008).There are many models for species distribution, however MaxEnt provides better results of species distribution predictions when compared to other models as it minimizes the relative entropy and works well with predictive distribution(Phillips & Dudik, 2008; Tarkesh & Jetschke, 2012).

The occurrence data for the species used in this study was accessed from the Global Biodiversity Information Facility (GBIF, 2015) and in the case of *Carijoa riisei*, additional records were added from new unpublished data collected by Fernando Rivera and Priscilla Martinez on the coast of Ecuador (NAZCA, 2015).

The environmental data was accessed from Bio-ORACLE(Bio-Oracle, 2015). This dataset consists of 23 environmental rasters including, Mean Chlorophyll, Mean Sea Surface Temperature, PH, Sea Surface Temperature Maximum, Sea Surface Temperature Minimum, Radiation, Phosphate, Dissolved O_2, Salinity, Chlorophyll Maximum, all these layers assist in the modelling of the distribution of marine species at a global scale (Tyberghein *et al.* 2012).

5.4.1 Maximum entropy modelling principal

The principal of maximum entropy is based on presence only data and provides a probability output that can handle sampling bias, therefore when characterizing an unknown distribution, the maximum entropy should always be chosen (Jaynes, 1957).

The following describes the maximum entropy modelling of species geographic distribution (Phillips *et al.* 2006). Allow π to be an unknown distribution over a finite set X where X is referred to as a point. The distribution π assigns a non-negative probability π(x) to each point *X*, and these probabilities sum to 1. Allow $\hat{\pi}$ represent an approximation of the unknown distribution. The entropy of $\hat{\pi}$ is defined as:

$$H(\hat{\pi}) = -\sum_{x \varepsilon X} \hat{\pi}(x) \ln \hat{\pi}(x)$$

Entropy is an important concept in information theory, it can be described as how much choice is involved in the selection of an event (Shannon, 1948), therefore a distribution with a maximum entropy would have more choices (Phillips *et al.* 2006).

MaxEnt generates probability distribution over pixels in the grid, it calculates the probability of occurrence, so the closer the model is to the species the better the probability outputs are. The model was trained using the same data as was being inputted into the model. MaxEnt can be cross-validated by replicating the number of runs for a single specie, for this research each species validated 10 times.

Marine species distribution models were carried out using MaxEnt and the high-resolution global environmental dataset for the 19 potential non-native species explained in Chapter 2 plus the new case of Cobia discussed in this chapter. Four of these potential non-native species were chosen and are discussed in subsections 7.4.2 through 7.4.5. The results of the remaining species are described in Appendix IV.

5.4.2Species distribution model for *Carijoa riisei* – Snowflake coral

The azooxanthellate octocoral *Carijoa riisei* (Duchassaing & Michelotti, 1860) is native to the Indo-Pacific and has been widely spread throughout the Hawaiian islands causing significant ecological impact since it was first detected from Pearl Harbour in 1972 (Concepción *et al*. 2010). Its rapid growth and vegetative reproduction allows this species to achieve high densities and compete with, and displace, native fauna causing substantial impact (Kahng *et al.* 2008). *C. riisei* was first reported in the Marine Reserve Galera San Francisco in 2011 on the coast of Ecuador (NAZCA, 2015). It has also been reported in the islands of Malpelo, Colombia (Sanchez *et al.* 2011), located 500 km west of continental Colombia and about 1200 km northwest from the Island of Darwin in the GMR. Since it was first reported in Ecuador *C. riisei* has spread to three marine reserves on the coast and is causing ecological impact to the biological communities in the region.

A total of 141 georeferenced occurrence records are included in the GBIF database for *Carijoa riisei* (GBIF, 2015) an additional 11 data points from the coast of Ecuador were added to the dataset (NAZCA, 2015) to give a total of 152 occurrence data points for *Carijoa riisei* worldwide (Figure 5.5).The high-resolution environmental data from Bio-ORACLE along with the occurrence data was inputted into the MaxEnt model to obtain the following outputs.

The 152 georeferenced occurrence records of *Carijoa riisei* are represented in the MaxEnt model (Figure 5.6). The suitability scale is represented from 0 to 1 with warmer colours illustrating areas of better predicted suitability habitat for this species. The white squares represent the training data, whilst the violet squares represent the test locations. The model produces a Receiver Operating Characteristic Curve (ROC) and an Area under the Receiver Operating Characteristic Curve (AUC) the latter is used to test the model performance, the maximum achievable AUC is less than 1. For all figures the scale starts at 0 which, indicates low habitat suitability (blue) and 1, which indicates high habitat suitability (red). In the model for *Carijoa riisei* the AUC was 0.981, meaning the models outputs show a good prediction. The most important contributions of the environmental variables were chlorophyll mean and sea surface temperature mean (Table 5.1). This species relies on primary productivity and temperature in order to be able to establish in a new habitat.

Figure 5.5: Globalgeoreferenced data on the distribution of *Carijoa riisei*

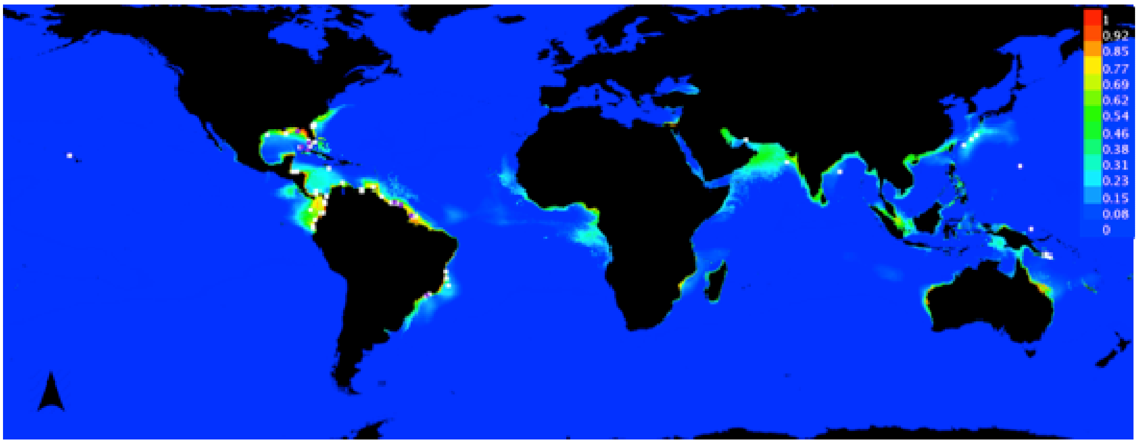


Figure 5.6: Habitat suitability map for *Carijoa riisei (*Occurrence probability 0 (blue) low, 1(red)high)

Table 5.1: Estimates of relative contributions of the environmental variables for *Carijoa riisei*

Variable	Percent contribution
chlomean	27
sstmean	21
chlomax	16.9
sstmin	13.1
ph	11.7
phos	4
dissox	2.2
nitrate	2
parmena	0.8
salinity	0.6
sstmax	0.6

Looking closely at the ETP region (Figure 5.7) the model illustrates the habitat suitability for *Carijoa riisei* all along the coasts of Costa Rica to the southern coast of Ecuador, including the Cocos Islands National Park, the Coiba National Park, the Malpelo Flora and Fauna Sanctuary and the Gorgona National Park (Figure 5.1). The model additionally illustrates some habitat suitability for *Carijoa riisei* in the GMR around the coastal areas of the archipelago. Ocean currents could disperse this species, but it is more likely that this species is introduced to the GMR by an anthropogenic vector such as marine traffic. The issue prevails that, there is a high risk of this species entering the GMR be it through natural or anthropogenic means.

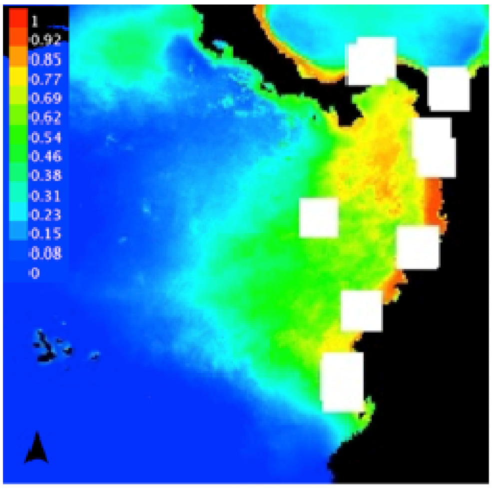


Figure 5.7: Enlarged section of the model for *Carijoa riisei* illustrating the GMR. *(*Occurrence probability 0 (blue) low, 1(red)high)

5.4.3Species distribution model for *Pterois volitans* – Lionfish

Pterois volitans has a native distribution in the Indo-Pacific that covers a large area expanding from Western Australia and Malaysia towards French Polynesia and the Pitcairn Islands. To the north it expands to South Japan, South Korea and to the south it expands to Lord Howe Islands off the east coast of Australia and the Kermadec Islands of New Zealand. This species is also found throughout Micronesia. (Randall *et al.* 1997; CABI, 2015). The introduction of *Pterois volitans* is thought to have been to the Atlantic Ocean through aquarium trade (Hare & Whitfield, 2003). The lionfish is now established along the Atlantic coast of the United States and the Caribbean. This species feeds on a variety of small fish, shrimp and crabs, which can cause serious damage to native ecosystems through predatory interactions. It is believed that the eradication of this species is almost impossible, but it could be controlled in some places (Hare & Whitfield, 2003).

A total of 1364 georeferenced occurrence records (Figure 5.8) are included in the GBIF database for *Pterois volitans* (GBIF, 2015) these are represented in the MaxEnt model (Figure 5.9). The model outputs show the AUC was 0.951, meaning the models outputs show a good prediction. The most important contributions of the environmental variables were nitrate and dissolved oxygen (Table 5.2).

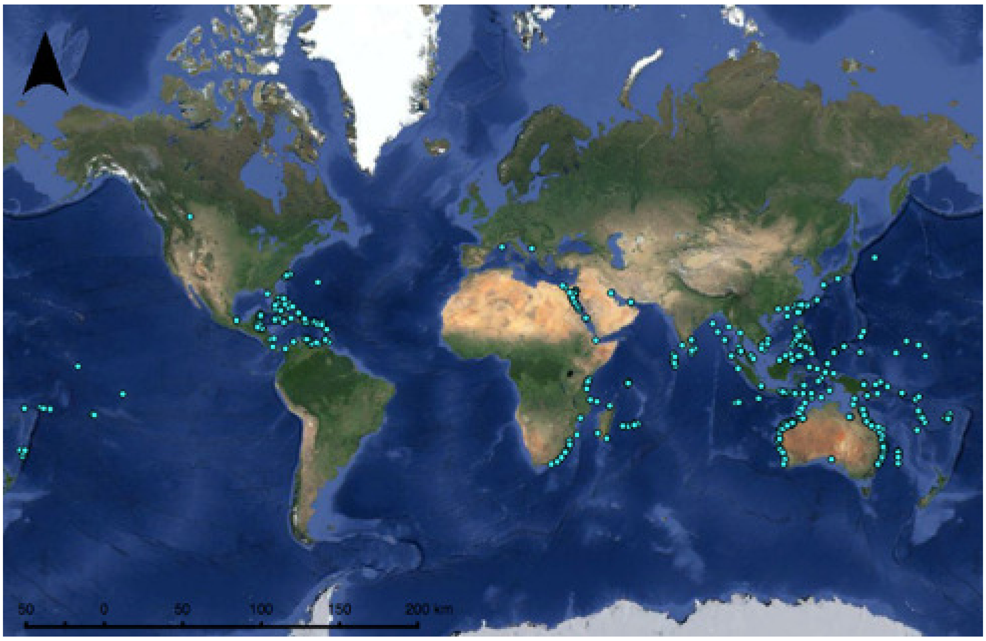


Figure 5.8: Globalgeoreferenced data on the distribution of *Pterois volitans*

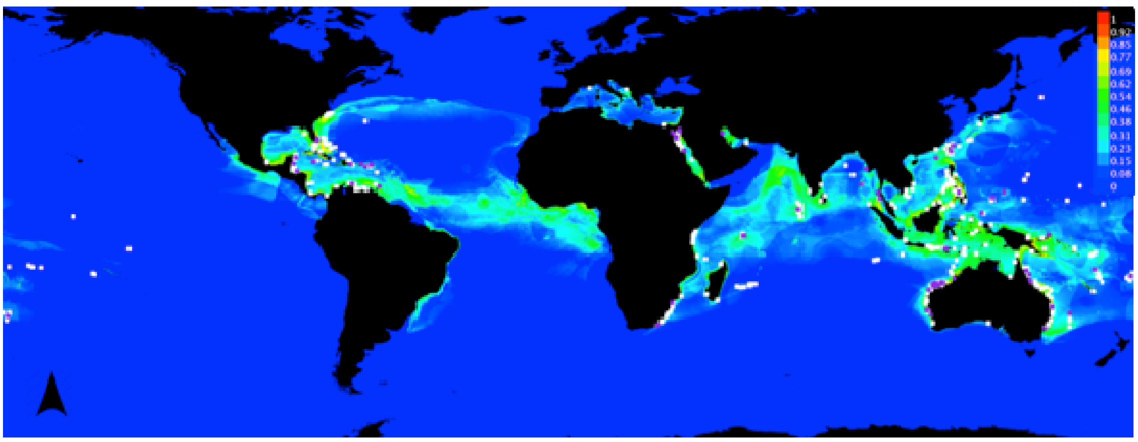


Figure 5.9: Habitat suitability map for *Pterois volitans. (*Occurrence probability 0 (blue) low, 1(red)high)

Table 5.2: Estimates of relative contributions of the environmental variables for *Pterois volitans*

Variable	Percent contribution
nitrate	40.6
dissox	18.4
chlomean	16.2
chlomax	8.3
sstmax	5.9
salinity	4
ph	3.3
phos	1.5
parmena	1.3
sstmean	0.4
sstmin	0.2

Primary productivity along with high levels of dissolved oxygen are necessary for healthy ecosystems and required by *Pterois volitans* in order to establish and survive in a new habitat. The present occurrence data does not show any presence of *Pterois volitans* in the ETP, the model predicts that the habitat suitability could expand up the coast of Mexico, Panama and Colombia. It is suggested that this range expansion would occur in the event of this species crossing the Panama Canal from the Atlantic Ocean to the Pacific Ocean. If this species was to establish a population in the ETP the risk of *Pterois volitans* expanding its range to the GMR is high due to the oceanic currents and larval dispersal.

5.4.4 Species distribution model for *Lutjanus kasmira*- Bluestripe snapper

Lutjanus kasmira is bright yellow in colour with four horizontal blue stripes and a maximum size of 40cm. This species has a large native geographic distribution and it can be found from eastern Africa through Polynesia. *L. kasmira* was intentionally introduced to Hawaii to enhance local fisheries, where it established, reproduced and spread throughout the archipelago competing and predating native species. This species like many other fish species produces buoyant eggs that can be dispersed by ocean currents, as can the larvae after the egg hatches (CABI, 2015).

A total of 651 georeferenced occurrence records (Figure 5.10) are included in the GBIF database for *Lutjanus kasmira* (GBIF, 2015). These are represented in the MaxEnt model (Figure 5.11). The model outputs show the AUC was 0.963, meaning that the models outputs show a good prediction. The most important contributions of the environmental variables were nitrate and sea surface temperature mean (Table 5.3).

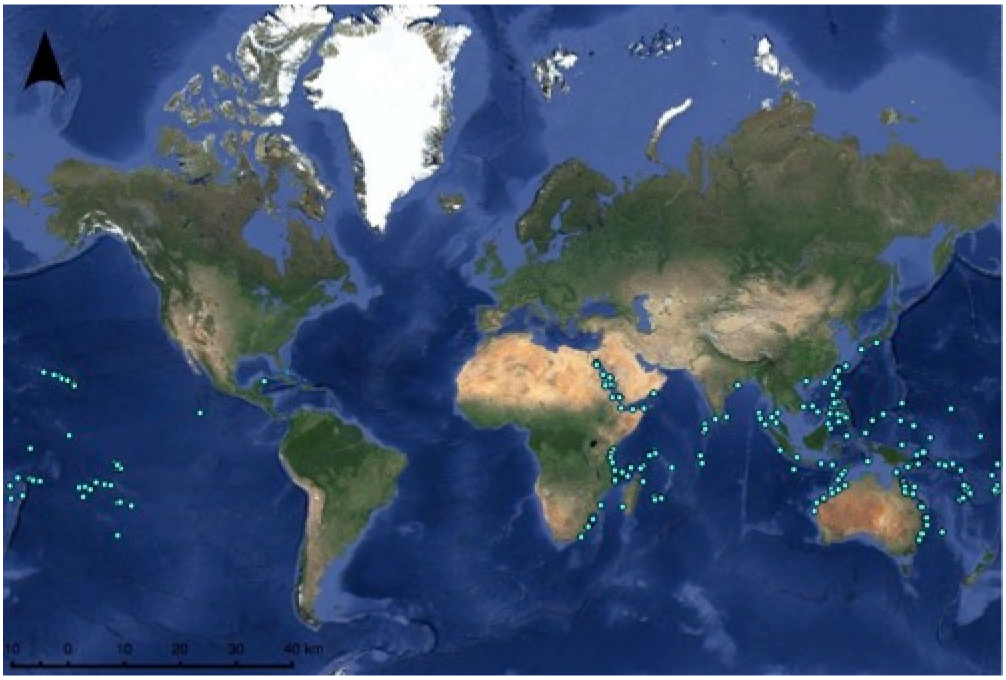


Figure 5.10: Globalgeoreferenced data on the distribution of *Lutjanus kasmira*

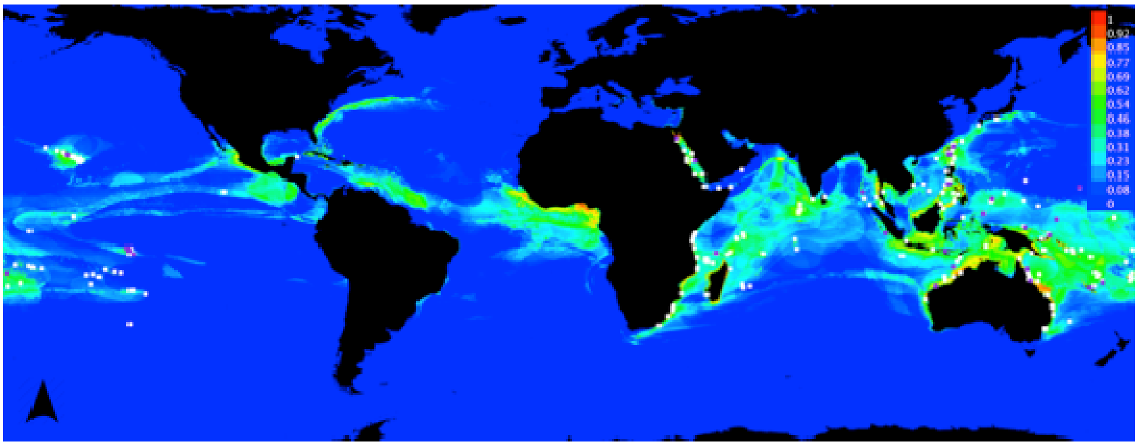


Figure 5.11: Habitat suitability map for *Lutjanus kasmira.(*Occurrence probability 0 (blue) low, 1(red)high)

Table 5.3: Estimates of relative contributions of the environmental variables for *Lutjanus kasmira*

Variable	Percent contribution
nitrate	21.3
sstmean	21.3
chlomean	18.6
sstmax	18.6
ph	14.1
salinity	6.4
chlomax	4.7
phos	3.1
dissox	3.1
sstmin	2.5
parmena	1.8

Lutjanus kasmira similar to other fish relies on primary productivity being high and is confined to a tropical or subtropical environment in order to be able to establish. Due to the fairly global distribution, the SDM for this model shows wide range of habitat suitability for this species. The model does not show the central islands of the archipelago as being suitable for this species. This could be due to the normal sea surface temperature mean for the GMR being too low for this species. However, the northern islands of Darwin and Wolf where sea surface temperatures are higher do show some suitability for this species. . The habitat suitability is illustrated in other regions of the ETP, mostly around Costa Rica and Panama. If an ENSO event took place in the region, the sea surface temperature would rise as discussed in subsection 5.2.2. This could open a window of opportunity for this species to migrate further south towards the GMR.

5.4.5 Species distribution model for *Rachycentron canadum* – Cobia

Subsection 5.3.1 described *Rachycentron canadum* in detail and stated that this species was not present in the ETP until the recent introduction of the species to the Ecuadorian coast for aquaculture. A total of 2098 georeferenced occurrence records (Figure 5.12) are included in the GBIF database for *Rachycentron canadum* (GBIF, 2015). For this model prediction the three aquaculture cage coordinates were added to the occurrence data to provide a total of 2101 records, which are represented in the MaxEnt model (Figure 5.13). The model outputs show the AUC was 0.962, meaning that the models outputs show a good prediction. The most important contributions of the environmental variables were chlorophyll mean and nitrate (Table 5.3).

Figure 5.12: Globalgeoreferenced data on the distribution of *Rachycentron canadum*

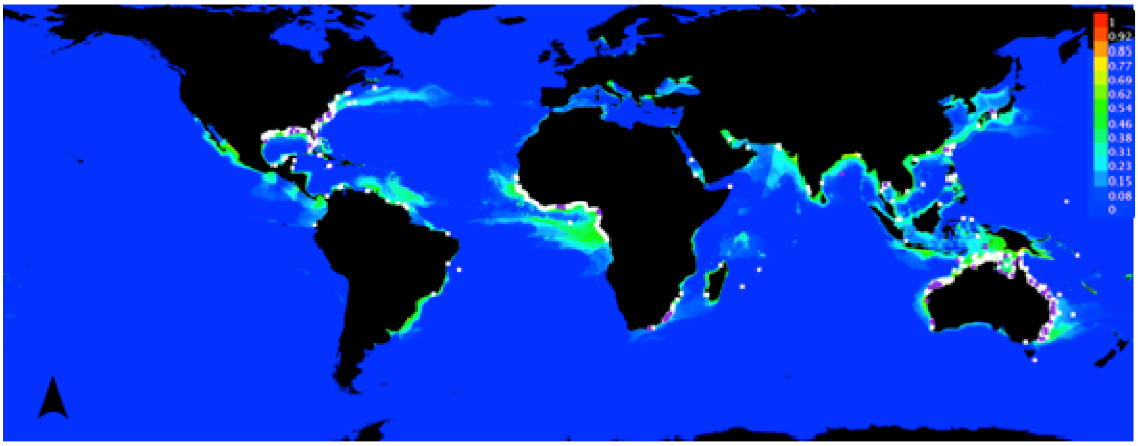


Figure 5.13: Habitat suitability map for *Rachycentron canadum. (*Occurrence probability 0 (blue) low, 1(red)high)

Table 5.4: Estimates of relative contributions of the environmental variables for *Rachycentron canadum*

Variable	Percent contribution
chlomean	35.5
nitrate	28.8
sstmax	15.8
ph	6.1
chlomax	5.7
salinity	2.3
sstmin	1.9
parmena	1.6
dissox	1
sstmean	0.9
phos	0.4

Chlorophyll concentrations in the ocean are very important as they form the underlying productivity base for the food chain. High levels of chlorophyll indicate nutrient rich water, *Rachycentron canadum* depends on nutrient rich water and primary production for a new habit to be suitable for range expansion as well as having temperature restraints.

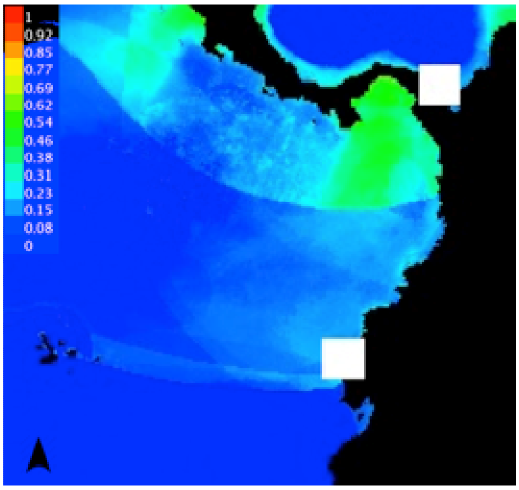


Figure 5.14: Enlarged section of the model for *Rachycentron canadum* illustrating the GMR. *(*Occurrence probability 0 (blue) low, 1(red)high)

The model shows (Figure 5.14) how the presence of this species on the coast of Ecuador predicts that the habitat suitability for this species can expand towards the GMR and up into the ETP to Colombia, Panama and Costa Rica. As discussed in section 5.3.1 this species could expand its range to the GMR and throughout the ETP due to the natural connectivity and current systems that exist in the region. Combining the habitat suitability and one of the possible transport vectors illustrates the high risk that exists of *Rachycentron canadum* entering the GMR.

5.5 SDM and climate change – a future scenario

A further scenario was modelled using the same methods as in section 5.4. However, in this scenario a set of environmental data was used to simulate conditions in the year 2100, and the data was again accessed from Bio-ORACLE, Scenario A2 (2100), (Tyberghein *et al.* 2012). *Carijoa riisei* was chosen as an example species for this SDM, MaxEnt and the occurrence data from subsection 5.4.2 was used to model habitat suitability for this species (Figure 5.15).

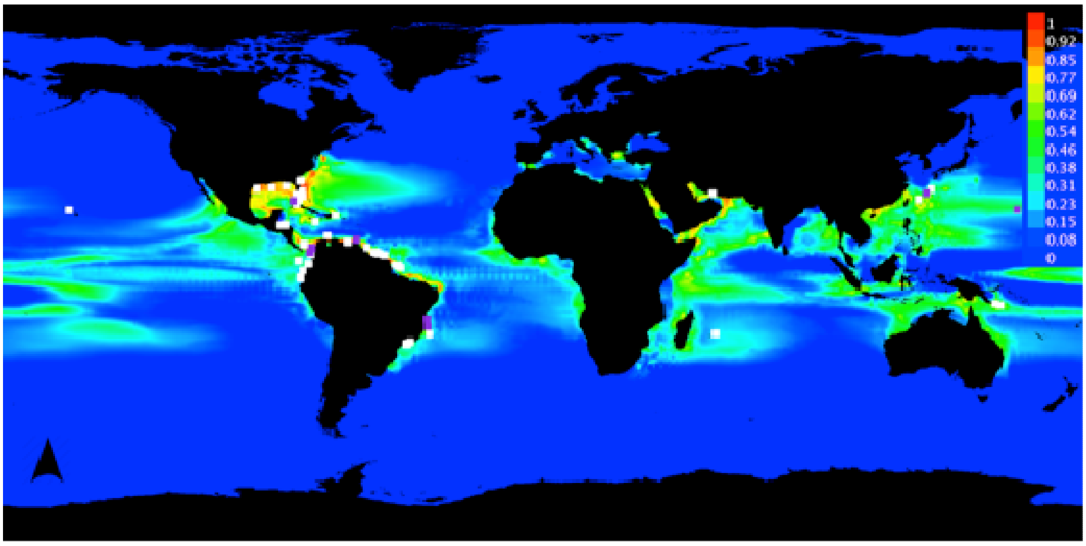


Figure 5.15: Habitat suitability map for *Carijoa riisei* in 2100. *(*Occurrence probability 0 (blue) low, 1(red)high)

The 2100 future scenarios was based on the IPCC global warming scenario based upon the A2 social-economic (high emissions) projections, more details in Jueterbock *et al.* (2013). The dataset includes global environmental gridded data including Sea Surface Temperature (SST) and Sea Air Temperature (SAT) derivatives (mean, minimum, maximum and range) (Jueterbock *et al*. 2013).

This scenario predicts the habitat suitability for *Carijoa riisei* in the year 2100, and the AUC was 0.952, which shows a good prediction for the projected species distributions. The minimum sea surface temperature and the monthly maximum surface air temperature, were the most important contributions for this model (Table 5.2). This model illustrates how this species range could expand under future conditions.

Table 5.5: Estimates of relative contributions of the environmental variablesfor *Carijoa riisei* in 2100.

Variable	Percent contribution
A2_sstmin_2100_m	48.7
satmax_mothly	12.9
satmaen_monthly	7.2
satmin_monthly	6.6
salinity	6.3
A2_sstrange_2100_m	6.1
A2_sstmax_2100_m	5.4
A2_sstmean_2100	4.6
satrange_monthly	2.2

5.6 Discussion

This chapter provides an insight into the different natural vectors that can influence range expansion of non-native species to the GMR along with natural processes enhanced by anthropogenic activity as well as using species distribution modelling to identify whether the GMR is a suitable habitat for a number of non-native species.

The geographic isolation of the Galapagos Islands has limited the immigration of new species historically enabling those few species that did arrive to evolve in the absence of competitors and predators. For this reason, oceanic islands are more prone to invasion by non-native species because of the paucity of natural competitors and predators that control populations in their native ecosystem. Islands often have ecological niches that have not been filled (‘open niche’) because of the distance from colonizing populations, increasing the probability of successful invasion (Loope *et al.* 1988). The marine species in the GMR have evolved in relative isolation and have a large number of endemic species. The exposure of oceanic islands to marine non-natives has often been discussed in invasion biology reviews (e.g. Elton, 1958; Simberloff, 1995; Inglis *et al.* 2006). For a non-native species to establish in a new environment there must be suitable environmental conditions, lack of predators and the availability of resources for the species to proliferate and these can be dynamic and highly variable in marine ecosystems. It has been suggested that island ecosystems often have accessible ecological niches that can be filled by opportunistic non-native species (Inglis *et al.* 2006; Wonham *et al.* 2000)

The connectivity through oceanic currents and the climatic variability that the archipelago experiences should be taken into account when talking about marine non-native species arrival, establishment and range expansion in this region. Marine non-native species arriving to the GMR through these vectors could find an open niche, establish and proliferate - changing the marine ecosystems, and in some extreme cases irreversibly. However, the arrivals of a non-native species to the GMR through natural vectors are considered to be natural arrivals, not introductions, as there is no anthropogenic component involved. Many ecologists would argue that this type of arrival should be considered part of the natural cycle no matter if the non-native species causes considerable ecological impact or not, therefore managers should not worry about these natural arrivals.

Within this chapter natural processes enhanced by anthropogenic activity are also discussed, some examples being climate change and marine debris. These types of vectors raise an interesting discussion as to how to categorize non-natives that get transported by them. Should these non-native species be considered introductions or natural arrivalsgiven to the fact both natural processes and anthropogenic actions are involved?

When looking at the earth's climate it can be said that it has been changing throughout history through natural periodic cycles, but it is now thought that due to the amount of greenhouse gases in the atmosphere resulting from human activity, global warming is expected to have a significant impact on our future climate (IPCC, 2007). Therefore, if climate change is attributed to anthropogenic elements, it can be argued that if non-native species are translocated due to climate change, these species could be considered introductions and, therefore, treated as threats to the marine ecosystem that need management strategies. It is uncertain how species might respond to climate change however if climate change was to affect the marine ecosystems of the GMR, this could give opportunistic species the advantage to expand overcoming previous natural barriers as well as having a window of opportunity to proliferate in a new affected ecosystem.

Similar is the case of marine debris, which is wastecreated deliberately or accidentally by humans that enters the natural environment. It is at this point that ocean currents and wind can spread marine debris and with it any non-native species on-board. As mentioned previously the ocean currents that influence the GMR are what enhance the connectivity between the GMR and the rest of the region. Therefore when looking at marine debris it can be suggested that the GMR receives debris waste through these current systems, and so the risk exists that non-native species could enter the GMR attached to this marine debris. The same question is raised: Should this type of arrival of a non-native species be treated as an introduction or as a natural arrival? It can be argued that certain species would not be able to expand their range naturally as far as the GMR without some aid, therefore, if it is the marine debris that assists with this translocation of a certain species, the arrival of this non-native species to the GMR would be considered an introduction and managers should treat this species as such.

The case mentioned in subsection 5.3.1 is an interesting one as the species *Rachycentron canadum* was intentionally introduced to the coast of Ecuador for aquaculture, however due to poorly maintained cages, this species escaped and now this species could potentially arrive to the GMR threatening the marine ecosystems. As above, the same question arises, if this species was to reach the GMR should this species be considered a natural arrival or an introduction? In this thesis, it is argued that this species should be treated as an introduction due to the fact it was originally introduced to the Ecuadorian coast by anthropogenic means, and if the introduction had not taken place this species would not be a threat for the GMR.

Great advances have been made in species distribution modelling, and in this chapter, the software MaxEnt was used to study the habitat suitability of 19 species that are considered a threat for the GMR as discussed in Chapter 2. Knowing the potential habitat suitability of a species can aid managers in predicting the risk of a non-native arriving to the GMR. Four species were evaluated in this chapter and the models for each were illustrated.*Carijoa riisei* and *Rachycentron canadum* were the two species that showed the most habitat suitability for the GMR followed by *Lutjanus Kasmira* that showed it could expand its range to the northern islands of Darwin and Wolf. The fourth species chosen was the lionfish *Pterois volitans*, with this species showing a possible range expansion into the ETP but does not expand as far south as the GMR. All these species need nutrient rich waters and favour warm sea surface temperatures, therefore, this could be a barrier that exists in the GMR due to the cold currents that reaches the islands from Chile and Peru. The situation changes when an ENSO event occurs or if future global climate change is taken into account, as sea surface temperatures raise the habitat suitability for these species with associated range expansion as seen with the example of *Carijoa riisei* using 2100 environmental data.

This chapter has discussed how non-native species can arrive to the GMR through natural vectors and how natural processes enhanced by anthropogenic activity can aid in the translocation of species. The habitat suitability of several species was examined which illustrated how ENSO events and potential future global climate change could aid in the expansion of non-native species. A crucial question that has been raised is how should non-native species be classified if they arrive through one of the discussed processes? In the event of a non-native species arrival to the GMR, it can often be difficult to know exactly how this species entered the GMR. Common fouling species could be attributed to anthropogenic vectors such as marine traffic. However, fouling organisms could also be introduced by marine debris that arrived to the GMR through natural current systems. Natural range expansion due to rising sea surface temperatures caused by anthropogenic actions can translocate non-native species as well, so how can decision makers know for sure if the arrival of a non-native species to the GMR is a natural arrival or an introduction? It is because of this uncertainty that this thesis suggests that all non-native species that arrive to the GMR should be considered as a potential threat to the marine ecosystems, and management plans should be put in place for the prevention, early detection and management of non-native species for the protection of the marine ecosystems of the GMR.

The managers of the GMR are encouraged to have early detection and rapid response protocols ready, similar to what was discussed in Chapter 5 for the species already present in the GMR. This year with the arrival of a strong ENSO event it is essential to conduct monitoring surveys to conducted directed searches for non-native species. Darwin and Wolf and the western side of the islands of Isabela and Fernandina are considered key places to conduct these surveys as these areas have been impacted during past ENSO events. Additionally, it is important to raise awareness with the community and the Galapagos National Park naturalist guides in order for them to report any possible new arrival.

In the event a non-native species was to arrive in the GMR rapid response protocols need to be implemented by the local managers and the removal of the non-native species would have to be immediate after the positive identification of the species. Early detection and rapid response protocols are tremendously important as removing a species once it has established can be extremely difficult and expensive as was discussed earlier in this thesis in Chapter 2.

The following chapter continues to examine existing and potential management strategies for non-native species arriving to the GMR and presents examples of management plans. Additionally, Chapter 6 also examines how this research on marine invasive species fits into the Ecuadorian government environmental policies.

Chapter 6:

Policy, Regulation and Management

6.1 Introduction

In Chapters 2 and 3 the impacts that non-native marine species can have on the marine ecosystem in the GMR have been discussed along with the possible transport vectors that can facilitate the arrival of these species (Chapter 4 and 5) as well as looking at the habitat suitability (Chapter 5). This chapter begins by examining the Ecuadorian government's environmental policy and concludes with a focus on risk assessments and management strategies for marine no-natives species in the GMR.

A synthesis of what local institutions in the Galapagos Islands are currently trying to enforce in terms of prevention, early detection and management of marine non-native species is discussed and a management plan for the prevention of the arrival and spread of non-native marine species to the GMR is presented along with a biosecurity plan conducted for the ABG. Risk assessments are discussed to illustrate the benefits of using these to provide decision makers a management tool for the mitigation of the possible impact of these species on the marine biodiversity and ecosystem services of the GMR.

6.2 The Ecuadorian government'senvironmental policy

The current government of Ecuador made several reforms to the countries Constitution in 2008, and the majority of Ecuadorian citizens ratified the new Constitution. The government decided that Ecuador should work towards a model based on well-being, a constitutional principle that is based on humans being part of the natural and social environment. Ecuador became the first country in the world to give rights to nature in its Constitution. This is stated in Title II, Chapter 7:

Articles, 71-74 (Constitución de la Republica Del Ecuador, 2008). In 2013, the National Secretariat of Planning and Development –*Secretaria Nacional de Planificación y Desarrollo* (Senplades) prepared the National Development Plan/ National Plan for Good Living 2013-2017 *(Plan Nacional de Desarrollo/Plan Nacional para el Buen Vivir 2013-2017)*: this plan which represents a clear vision and a guide to what the government aspires to accomplish by 2017 (Senplades, 2013).

The MAE, with the implementation of the Good Living model, seeks to strengthen sustainable development such as sustainable production and consumption, air pollution, climate change and biodiversity protection. MAE presented the National Biodiversity Strategy with the main objective to increase and ensure fair and equitable access to the benefits of ecosystem services associated with biodiversity and conservation in Ecuador. Within this strategy there are four specific objectives:

- Incorporate biodiversity and ecosystem services in the management policies.
- Reduce the inappropriate use of biodiversity to ensure conservation
- Distribute benefits brought by biodiversity and ecosystem services in a fair and equitable manner.
- Strengthen knowledge management and national capacities to ensure innovation in the sustainable use of biodiversity and ecosystem services (MAE, 2015b).

In the Galapagos Islands MAE is represented by two institutions: (i) the DPNG who are responsible for the administration and management of the islands ecosystems in order to ensure the conservation of the islands and the correct use of ecosystem services (DPNG, 2015b) and (ii) the ABG, which is in charge of controlling, regulating, preventing and reducing the risk of the introduction, movement and dispersal of non-native organisms that might threaten human health, the terrestrial and marine ecosystems, the integrity of the islands and the conservation of biodiversity of the Galapagos Province (ABG, 2015).

The Constitution of Ecuador establishes in article 258 that the province of Galapagos will have a special government regime whose administration will be the responsibility of the CGREG (Constitución de la Republica Del Ecuador, 2008). The CGREG is responsible for the administration of the province, land use, resource management and the organization of activities carried out in the Galapagos Islands in order to ensure the conservation of the natural heritage and promote 'Good Living'.

The DPNG created a new Management Plan for the Protected Areas of Galapagos and Good Living in 2014, which comes from the National Plan for Good Living (DPNG, 2014b; Senplades, 2013). For the first time in the history of Galapagos Islands, the new management plan highlights the importance of ecosystem services and their sustainability. This management proposal aims to generate positive changes in the Galapagos resident population while implementing, social and environmental responsibility to achieve good living.

6.3 Environmental policy and marine non-native species research

The research conducted for this thesis on marine non-native species in the GMR falls within the national planning to help preserve the important biosecurity of the GMR by carrying out risk analysis studies of potential marine invasions. Objective 7 of the National Plan for Good Living 2013-2017 ensures the rights of nature and promotes regional and global environmental sustainability (Senplades, 2013). This research is in accordance with the DPNG Management Plan for the Protected Areas of Galapagos and Good Living, Specific objective 5.1.4 as it increases the interdisciplinary scientific knowledge of the biology and ecology of populations and communities of non-native species and their relationship to the Good Living of the community in order to have a prevention, mitigation, eradication system in place (DPNG, 2014b)

The research conducted within this thesis is represented within several articles presented by the MAE and the National Biodiversity Strategy in the Convention on Biological Diversity Report. Chapters 2 and 3 provide a baseline study, monitoring and risk assessment tools (CBD Art. 7) with the aim of establishing a preventative program in the GMR (CBD Art. 6). The research was conducted in the GMR looking at the prevention of non-native marine species arriving to the GMR and monitoring potential impacts (CBD Art. 8h), this has a direct benefit for sustainable local livelihoods (CBD Art. 8i and 8j). Part of this research (Chapters 3, 4 and 5) has been working with local institutions and sharing knowledge from this research (CBD Art. 12), and this has been done in close collaboration with international experts and technical resources (CBD Art. 16 and 18). A lot of work has been done on the dissemination of knowledge from this thesis (Chapters 3, 4 and 5) within the local and international community (CBD Art. 13) (MAE, 2015b).

6.4 Marine biosecurity in the GMR

We all depend on a healthy marine environment to thrive but damage to the environment may affect biodiversity negatively and consequently lead to huge financial losses. Therefore, an effective biosecurity plan can help prevent this from happening. The value of a healthy marine environment has been widely acknowledged and understood for some time. However, what is changing is that we are increasingly aware that the biodiversity of our seas provides a wide range of ecosystem goods and services that are important for our lives and livelihoods. Non-native marine species threaten marine ecosystems and ecosystem services, which is why implementing biosecurity and action plans to prevent or mitigate this threat is of great importance for the implementation of the Good Living model.

From a terrestrial stand point, the Ecuadorian government's biosecurity, for the most part, is intelligent, well organised and seems to be effective, with a number of publications detailing observations of introduced terrestrial plants (e.g., Buddenhagen, 2006; Jager & Kowarik, 2010) and animals (e.g., Cruz *et al.* 2005; Carrion *et al.* 2011) eradications and impacts (e.g., Schofield, 1989; Itow, 2003; Renteria *et al.* 2012; Kueffer *et al.* 2010), invasion risks (e.g., Gottdenker *et al.* 2005), and ecosystem restoration, management and conservation strategies (e.g., Gibbs *et al.* 1999; Causton *et al.* 2006). In contrast to the terrestrial systems, marine biosecurity activities lag behind and are consequently less well managed, but not for a lack of effort (Campbell *et al.* 2015). The CDF, the DPNG and the ABG have been working together to improve the marine biosecurity standards for the GMR, and some evident changes have taken place. The following are some examples and descriptions of the changes that have taken place to improve biosecurity in the GMR.

Altered pathways and exposure to threats:

- No longer do international cruise vessels come into the Galapagos waters, international tourists now are required to fly in and then join cruises or stay on the populated islands; In recent years island based tourism has expanded (de Groot 1983; Baine *et al.* 2007), with many inter-island day trips now available (Campbell *et al.* 2015).

Increased site access:

- The number of tourist sites available has increased from 35 land sites in 1983 (de Groot, 1983) to include 169 marine sites in 2014 (DPNG, 2014b), with a consequence that the connectivity between islands has increased dramatically (Campbell *et al.* 2015).

Pre-border and border inspections:

- Vessels entering the islands are subject to hull inspections to help manage the transfer of introduced species from mainland Guayaquil to the Galapagos Islands;

- Vessels that fail hull inspections must leave the GMR waters and be cleaned before re-entry into the Galapagos;

- Annual marine traffic analysis is undertaken to examine the cargo boats and oil tankers that commute between the islands, and mainland Ecuador, as well as tourist, fishing, patrol, and private boats that can arrive from mainland Ecuador and international ports (Campbell *et al.* 2015).

Post-border species surveys and surveillance:

Following the outcomes of this thesis, a number of standardised monitoring approaches have been established to help with the early detection of invasive species. This includes:

- Annual introduced marine species monitoring occurs at the 5-main ports in the GMR
- Directed searches for marine invasive species at key sites around the GMR
- Deployment of settlement plates in the port of Santa Cruz in 2015, using the Smithsonian Environmental Research Centre (SERC) methodology. This will enable comparisons with other international locations that also use settlement plates. Settlement plate deployment will be extended to the other four ports in the GMR, and later to key visitor sites around the GMR and ports in mainland Ecuador (Campbell *et al.* 2015).

6.5 Strategic workshop in the GMR: first international workshop on marine bioinvasions of tropical island ecosystems

In order to showcase the importance of a biosecurity plan to the authorities, part of this research was to organise an international workshop, with experts on marine bioinvasions from different parts of the world, and authorities from a number of Ecuadorian Government institutions. This workshop provided the opportunity to share data, points of view and approaches to scale the current and future status of marine biological invasions of tropical islands in general and the GMR in particular, and to identify top priority actions to protect the Galapagos Islands from marine invasions.

Increasing tourist pressure and interconnectivity between the Galapagos Islands and other regions has led to the initiation of this workshop where one of the goals was to develop a marine biosecurity management plan that would help ready the Galapagos Island environmental managers to anticipate the prospect of an invasion. Plans for governance, communication, rapid response decision tools, risk analyses, tropical marine island bioinvasion trends and action plans for pest species such as *Carijoa riisei* (already present on the mainland coasts and at marine protected areas nearby) were discussed and initiated (Campbell *et al.* 2015)

The workshop focused on two goals, to attempt to cover various aspects of marine bioinvasions in tropical island ecosystems:

1. To assess our knowledge about marine invasive species in tropical archipelagos in general and focus on the GMR and discuss what is being done and what remains to be done.

2. Produce a strategic research plan for Galapagos, informed by all participating institutions to aid decision makers with the management of marine non-natives species in the GMR (Appendix VII).

6.5.1 An action plan to minimize risks of marine invasive species introduction into the Galapagos Marine Reserve

(published as: Keith, I., &Toral, V. (2015). *Action plan to minimize risks of marine invasive species introduction into the Galapagos Marine Reserve*. Technical Report No. 1 2015. Charles Darwin Foundation, Santa Cruz, Galapagos, Ecuador. ISSN 1390-6526).

Considering the incalculable risk posed by marine non-native species to the conservation of ecosystems and species in the GMR, the negative impacts must be minimized through research and strategic management actions. For this purpose, this action plan outlines the four research questions that Government institutions and bioinvasion experts suggest must be answered in order to develop a strategy to prevent and manage marine non-native species. Each section has a research question and a brief summary. The questions were discussed during the workshop by all the participants and a consensus was reached as to which questions were the most important.

Question 1: How many non-native marine species are established in the GMR?

This research has produced a list of 9 non-native species that are established in the GMR (Chapter 3). As research continues in this field and in the GMR, it is very likely that the identification of more non-native species will take place and, therefore, the list will expand. The continuation of this research is key in order to have up to date management strategies for the protection of the marine ecosystems in the GMR.

1.1 Conducting directed searches for marine non-natives in the GMR

Marine ecosystems in Galapagos feature unique biological communities, with a high incidence of endemic species, which lack defence mechanisms against non-native species. Additionally, the absence of physical barriers limiting natural dispersion (such as mountain ranges and rivers in the terrestrial environment) in the ocean around Galapagos facilitates the spread of these species within the GMR. It is important to conduct directed searches for marine non-native species in key sites around the GMR for the prevention and early detection of potential problematic non-native species that could arrive and affect the marine ecosystems.

1.2 Monitoring of the main ports in the GMR

The Galapagos Islands, because of their geographic isolation, depend on cargo ships from mainland Ecuador to supply the resident and tourist populations' basic needs. These ports can be the port of entry for non-native species that are transported by marine traffic to the islands (Chapter 4). Port monitoring is considered of high priority because numerous potentially invasive organisms can adhere to marine structures in ports after being introduced by marine traffic.

1.3 Monitoring abundance and distribution of non-native species present in the GMR

Key sites have to be selected around the GMR to monitor the arrival and possible spread of marine non-native species. It is necessary to research what species could arrive to the GMR given the rapid expansion of marine traffic, the connectivity through oceanic currents and the climatic events that occur in the region (Chapter 4 and 5). It is of high priority to continue long-term monitoring, to keep track of non-native marine species established in the RMG, to determine whether their abundance and/or distribution change over time and environmental conditions.

1.4 Deploying and analysing settlement plates

Many marine species have larval phases in their development, which can facilitate their dispersal. When they end their larval stage, they look for substrates to settle and continue on to their next phase of development. Settlement plates deployed on floating docks are key in extending monitoring techniques of port structures, this method allows for early detection of non-native marine species. This methodology is used around the world therefore, results can be compared between regions to expand the knowledge of the non-native species present. A fundamental component to this methodology is counting with the taxonomic expertise in order to evaluate the identity and abundance of the species on the settlement plates.

Question 2: How can non-native species arrive to the GMR?

Marine non-native species rely on vectors to transport them from one region to another, several anthropogenic and natural vectors exist and between them, they are responsible for the translocation of non-native species around the world (Chapter 4 and 5). This research suggests marine traffic as the most important anthropogenic vector for the transport of non-natives to the GMR at this time. However it is unclear whether climate change or other vectors might escalate the translocation of non-native marine species to the GMR in the future therefore continuous research of possible vectors is necessary for the prevention of non-natives entering the GMR.

2.1 Risk analysis of maritime traffic entering the RMG

The number and frequency of vessels have fluctuated widely in recent years. An analysis of vessels and inspections needs to be conducted to prevent the introduction of non-native species to the GMR and to have a record of which biogeographical regions species could be arriving from. Port hotspots in the ETP region need to be identified in order to be able to conduct risk assessments.

2.2 Analysis of current systems in the GMR and the ETP to illustrate the connectivity in the region

The development of an ocean circulation model for the connectivity between the Galapagos Islands and the ETP will help determine the risk of species dispersal through oceanic currents. This tool could predict invasions of all areas of the ETP region and propose a regulatory framework and protocols to prevent introductions of marine invasive species.

2.3 Identify possible invasions because of climate change and climate variability

The archipelago has witnessed significant climatic variations through El Niño events for centuries. Establishing a predictive model aimed at identifying the possibilities of new invasive species reaching the GMR due to extreme climatic effects could help strengthen prevention and early warning protocols. Each individual species has an‘environmental niche’, a tolerance range of temperature, salinity, nutrients, depth and habitat types and substrate where they settle. Using this information and combining it with the biophysical information of the GMR a sensitive map with possible areas of invasion could be created for the archipelago.

2.4 Analysis of marine debris

Marine debris can transport non-native species and threaten remote islands around the world; a perfect example are the Galapagos Islands. Non-native species can adhere to floating waste in the sea, and this debris can be carried to different regions. Good examples of marine debris are ghost nets that are lost at sea and carried to different parts of the world by oceanic currents as well as the fish aggregating devices (FAD) that are left behind by illegal fishing boats.

Question 3: What would be the most efficient measures in reducing the risk of non-native species arriving or spreading in the GMR?

3.1 Cargo ships

Conduct a risk/benefit analysis of creating a centralized cargo port for the entire archipelago where all cargo ships from continental Ecuador arrive and transfer the cargo to local boats for distribution. A baseline study of the proposed site would need to be conducted, and monitoring protocols for the port and vessels put in place. Developing contingency plans for high-risk species based on research findings from questions 1 and 2 and develop a strategic plan.

3.2 National and international vessels

Raise national and international awareness on the importance of vessels having clean hulls in order to enter the GMR. Create a quarantine area separate from the main port structures and other vessels in each port to carry out inspections by local authorities.

3.3 Tourist vessels within the GMR

The implementation of regulations for washing diving and snorkelling gear, as well as zodiac tenders between visitor sites in the GMR, is key in order to minimize the risk of spreading marine non-native species between sites.

3.4 Ballast water discharge in the GMR

The MTOP through the SPTMF and in coordination with the GNPD created the Ecuador Task Group (GTE) that seeks to establish a national strategy to assess the problem of introducing non-native species through ballast water from international marine traffic.

3.5 Create an Emergency Operations Committee for marine non-native species

Creating an Emergency Operations Committeefor marine non-native species is of high priority. This committee must be created engaging all relevant institutions, and its protocols must be decided and approved among all relevant parties. Prevention is the best control method to avoid an invasion from a marine non-native species however in the event that a non-native species arrives to the GMR early detection, and rapid response protocols are key for the rapid and correct mitigation of a potential invasion.

3.6 Hull inspection and cleaning protocols

Vessel hull inspection protocols must be created and discussed among all institutions that have the directive to inspect vessel hulls. Capacity building workshops for ship inspections need to be conducted periodically to ensure correct inspection and safety. Regulations and safety protocols have to be put in place for the cleaning of hulls of tourist vessels that fail to pass the hull inspection.

Question 4: What is the risk of *Carijoa riisei* arriving to the GMR and how can it be prevented?

Carijoa riisei has been reported in continental Ecuador and on the island of Malpelo in Colombia. Nazca Marine Research Institute has reported this coral rapidly expanding along the Ecuadorian coastline, increasing the risk of this species arriving in the RMG.

4.1 Conduct a monitoring program for Carijoa riisei on the cost of Ecuador

It is a matter of high priority to research and monitor the distribution of *Carijoa riisei* to learn the degree of invasion on the coast of Ecuador and determine the risk posed by this species for the RMG. After ascertaining the distribution of *Carijoa riisei,* management strategies can be put in place to manage this species, and determine the necessary control measures.

Recommendations from all institutions that participated in the workshop:

- Plan to prevent non-native species from entering the RMG: This is a serious problem not only for Ecuador. If we are to prevent non-native species from invading Ecuadorian ecosystems, management strategies must be established with neighbouring countries (Peru & Colombia).
- ECUADOR TASK FORCE (Grupo Tarea Ecuador - GTE). A symposium was held in continental Ecuador to establish the laws controlling Globallast. It is recommended that informative meetings take place, to plan and implement commitments that each institution on the GTE may have to undertake.

- Create a manual that explains the procedures to follow for the different stages involved in a marine bioinvasion, from vectors to existing management strategies to dealing with established species and new arrivals.
- Mechanisms to control *Carijoa riisei*: An "Invasive Species Action Group" could be created and trained to control and/or eradicate non-native species, using knowledge from countries where this species has caused an impact.
- Hull inspections: Establish work groups in each port with inter-intuitional personnel to conduct hull inspection, identification of species and make relevant decisions regarding the species present.
- Installing settlement plates on Continental Ecuador: Training personnel working with institutions on the mainland would be the best option, thereby generating requirement in their annual operating plans so that funds can be allocated for this activity.
- It is important to monitor intertidal zones, which are among the localities where invasive species may settle.
- The key issue with marine non-native species is to assess the damage that they are causing to native biodiversity and the marine ecosystems.
- Intensify control over anthropogenic activities involved in shipping traffic.
- Encourage each tourism company to have fresh water chlorinated pools to wash equipment used for tourist activities (diving/snorkelling equipment) to prevent transmission of species from one visitor site to another.
- Support research regarding this issue and encourage citizen awareness.
- Ecuadorian Navy vessels visiting the islands may be significant vectors transporting foreign species. It is recommended that the Ecuadorian Navy carry out protocols to clean and inspect their hulls before entering the RMG.
- Publicity and education campaigns must accompany the research.
- Examining the potential climate change or possible implications of ENSO events within a marine invasion context;
- The use of predictive models to determine which species may arrive in the GMR and to determine natural connectivity in the Eastern Tropical Pacific via oceanic modelling;

- Prepare for a range of response plans for potential marine invasive species should they arrive in the Galapagos;
- Strengthening multi- institutional relationships between the CDF, GNPD and to create protocols for hull inspections and movement of dive/snorkel equipment within the GMR
- The creation of a (marine focus) rapid response team that involves local institutions.

6.6 Risk analysis and ranking systems for biosecurity

Risk analysis is often divided into two components, risk assessment, and risk management. Risk assessment is the process by which risk is measured and can be conducted before the occurrence of any events that could cause the risk or after the possibility of risk is incurred (Carlton, 2003). In Chapter 4 a risk assessment was conducted for non-natives being transported on hulls based on a species exposure analysis. This section describes risk assessment using ranking systems to evaluate impacts and potential invasiveness of non-native species. Risk assessment systems have been used around the world to try to mitigate non-native species arrivals (Brown, 2009). Ranking systems help identify the most problematic non-native species in or near the area in question and aid stakeholders in decision-making. Impact assessments can be based on a series of questions: 1) ecological impacts, 2) economic impacts, 3) human health impacts, 4) invasive potential and 5) difficulty of control. Each section gets a score, a high score corresponds to a species that can cause a great impact on the environment. The other part of the assessment deals with the current ability to prevent and take early action, questions related to entry and transport pathways, current distribution, policy and outreach measures already in place are asked to help facilitate prevention or rapid response. (Brown, 2009) The following section presents an example of a biosecurity plan using the ranking method for risk assessment.

6.6.1 Biosecurity plan for the "Copa Galapagos 2014": management of hulls and port structures to prevent the introduction of non-native species to the GMR.

(published as: Keith, I., & Martínez, P. C. (2014). *Plan de bioseguridad marina para la Copa Galápagos 2014, Manejo de cascos y estructuras para prevenir la introducción de especies no-nativas a la Reserva Marina de Galápagos*. Technical Report. Charles Darwin Foundation, Santa Cruz, Galapagos, Ecuador.

The Copa Galapagos is a sailing regatta that takes place once every two years between the Salinas Yacht Club in continental Ecuador and the Galapagos Islands. It has been running for 30 years and attracts competitors from Argentina, Chile, Peru, the Unites States of America and Ecuador. In the past, there has been no biosecurity control prior to this regatta. As part of this research, the author considered it would be good practice to create a biosecurity plan for the ABG to implement before the start of the regatta, this way the ABG technicians could get hands on experience and be able to repeat the process in the future. The main objective of this plan was to prevent the introduction of non-native species to the GMR. The biosecurity was based on a similar marine biosecurity plan conducted in England and Wales (Payne *et al.* 2015) and adapted to fit the conditions in Salinas Ecuador. The questions for the biosecurity plan were discussed amongst the ABG and PNG before finalizing the biosecurity plan.

It is important to know the site from which the boats are arriving or departing from, in this case, the Salinas Yacht Club marina located on the coast of Ecuador. Good knowledge of the site helps create a more effective biosecurity plan. The following questions were deployed as part of the surveys and assessment:

I. Site Information:

1) What is the salinity of the water at the site?

Most animals and algae cannot tolerate freshwater for long periods of time. This means that if there is a spring of fresh water on site, which reduces the salinity, this will make the area less hospitable to non-native species. The greatest risk is when the water is totally saline.

2) How many artificial structures are in the water?

The risk of introduction and establishment of marine non-native species is increased by the presence of artificial structures, such as concrete ramps, floating docks, hulls, chains and buoys as these species typically prefer to settle in the artificial structures instead of natural surfaces. Any structure that has been in the water for a few weeks, especially in the months of hot water without antifouling paint would be at risk.

3) Are there non-native species on the site?

It is very likely that non-native species are already present around the Salinas Yacht Club, so the biosecurity plan should focus on reducing the risk of introducing new non-native species to this site, and consider how best to prevent non-native species becoming invasive and getting transported to a different region.

If there are records of non-native species in the area, these should be taken into account in the biosecurity plan. However, in the case that there are no records of non-native species in the area, the plan should follow a precautionary principle and assume that non-native species could be present and act as if they were.

In addition to thinking about the site, the artificial structures and the non-native species that are already present, it is also important to consider how non-native species could be introduced. What is the marine traffic in the area, the routes and what marine equipment is moved around the site?

II. Marine traffic information:

It is important to gather information about the vessel arriving, including:

1. Name of vessel: 2. Type of vessel: 3. Length:

4. Port of origin: 5. List of last ports of call: 6: Date of arrival:

7. Date of departure: 8: Is fouling visible on the hull:

The next step is to examine the risks posed by the arrival of the vessel by answering a series of questions during the inspection of the vessel and using a ranking system. Each question has a HIGH, MEDIUM or LOW ranking system and in order to assess the risk the questions must be asked, for example, has the vessel arrived from a port from a far away/different region? If the answer is YES, then this vessel is of HIGH risk however if the vessel has arrived from a neighbouring port then the vessel would be of LOW risk. If the inspector is not sure how to rank the risk, it is advisable to rank it as HIGH in order to assess the vessel further in order to prevent the introduction of marine non-native species.

	HIGH	MEDIUM	LOW
1. Has the vessel arrived from a far away/different region?			
2. Has the hull been treated with antifouling paint in the last 12 months?			
3. Is there biofouling present above the watermark?			
4. Is there biofouling below the watermark?			
5. Does the vessel have organisms present on the hull, rudder, propeller, intake pipes etc.?			
6. Has the vessel arrived from a region with similar environmental conditions?			
7. Has the vessel arrived from a region that has reported problematic non-native species?			
8. Did the vessels spend a long period of time stationary in the same place?			
9. Is it a slow moving vessel? (e.g., a barge)			
10. During the inspection dive were organisms found on the vessel?			

The biggest risk for the introduction of non-native species occurs when vessels arrive from another country or region with similar environmental conditions (e.g., temperature, salinity). Many of these boats often have a visible line of green algae round the watermark this should be considered of LOW risk, the incrusting species that can be found on the vessels hull, propeller, intake pipes, etc. are the species that are considered HIGH risk. During inspections it is very important to check these areas for incrusting species and photographs, video and collections of organisms must be taken for identification in the laboratory. When collecting an organism it is important to make sure to collect the entire organism and not allow any to fall to the seabed.

III. Inspection Pass/Fail:

Once the vessel inspection is completed, the ABG inspector will have the authority to grant or deny the permission to participate in the Copa Galapagos. If a vessel does not meet the clean hull requirements, the vessel has the opportunity to clean the hull and be subject to another inspection. The port authorities and ABG will indicate the area where hulls can be cleaned.

IV. Inspection of hulls and artificial structures:

Inspections must be conducted on all artificial structure including dock and buoys. The inspection should begin from above the watermark to the seabed. It is also important to conduct inspections on the artificial structures of the marina since vessels moor at these docks and the transfer of organisms can occur. The following questions should be answered and ranked with the following key:

High: > 50% of species visible,

Medium: <50% of species visible,

Low: few species visible

	HIGH	MEDIUM	LOW
1. Are there species visible on the docks?			
2. Are there species visible on the buoys?			
3. Were species found during the inspection of artificial structures?			

V. Recommendations:

The regatta event along with the biosecurity plan for hull and dock inspections was a success. The regatta participants were interested and motivated to participate and the ABG has since continued using this biosecurity plan for hull and dock inspections. The complete technical report can be seen in Appendix VIII. The following recommendations are based on field observations and meetings held with the ABG technicians after the event.

• Gather biosecurity information on arriving vessels as soon as possible; including the port of origin, last ports of call and date of the last antifouling treatment. If possible prior to arrival via radio.
• Have a quarantine area, if possible with fresh water for ships arriving from far away/different regions.
• Conduct a quick visual hull inspection of high-risk vessels from pontoon/dockside
• Provide biosecurity information to regatta participants prior to arrival so they can assess their vessel and be prepared for the inspection on arrival
• Request the owners of the vessels not to discharge bilge or ballast water in the marina.
• Facilitate a quarantine area for hull cleaning.
• In the event that the boat is taken out of the water for cleaning use a tarp to collect scrapings from the hull and ensure that these do not enter the ocean.

6.6.2 BowTie methodology for risk assessment

Risk assessment tools like the previous one discussed a risk analysis ranking system that can be used to manage risk. A further risk assessment tool, which was developed by petrochemical industries to help with their risk assessments of hazard, is called the BowTie method (Pidgeon *et al.* 2007). The BowTie diagram (Figure 6.1) is a useful tool for risk assessment as it illustrates all threats and consequences of a potential impact and relates them in a simple diagram, this allows decision makers to manage the risk and make informed decisions. The BowTie method allows for all credible scenarios to be assessed, whether the event has already occurred or not (Pidgeon *et al.* 2007). A BowTie can demonstrate how a threat is linked to a top event (Risk event to be avoided) and outlines the different pathways as to what threats can lead to the top event. In the event that the Top event takes place, the diagram outlines the pathways to consequences from the top event occurring can be seen. In the BowTie method, it is possible to introduce barriers to prevent or avoid the threat leading to the top event as well as barriers from the top event to reduce or mitigate against the consequences (Fenna, 2015).

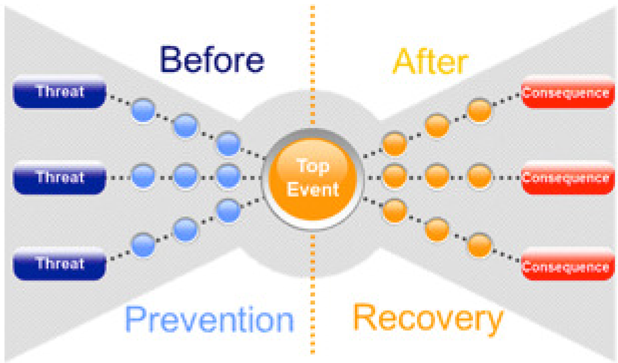


Figure 6.1: Illustration of the BowTie methodology (Risksoft, (Pidgeaon *et al.* 2007))

Using data gathered for this thesis, the BowTie method was applied for assessing the risk of the arrival of a non-native species to the GMR (Figure 6.2). The top event in this example is the arrival of non-native marine species illustrated in the red circle in the middle. The threats are on the left-hand side marked in orange boxes: these identify the possible vectors that could translocate the marine non-native species to the GMR. At this stage, the risk assessment is looking at prevention measures, which is why barriers are set up in order to prevent the event occurring. The barriers are the small green boxes that illustrate different control measures that can be implemented to each individual threat to create early warning systems and rapid removal/evacuation to avoid the species establishment. The right-hand side of the BowTie illustrates the consequences in the blue boxes, these boxes show examples of events that could occur after the arrival of non-native marine species to the GMR. At this point, the risk has increased, and mitigation has to start to be able to prevent greater impact and start the recovery of the impacted scenarios. The large green boxes in front of the consequences boxes illustrate another set of barriers that have to be put in place to prevent the consequences increasing and the risk maximizing.

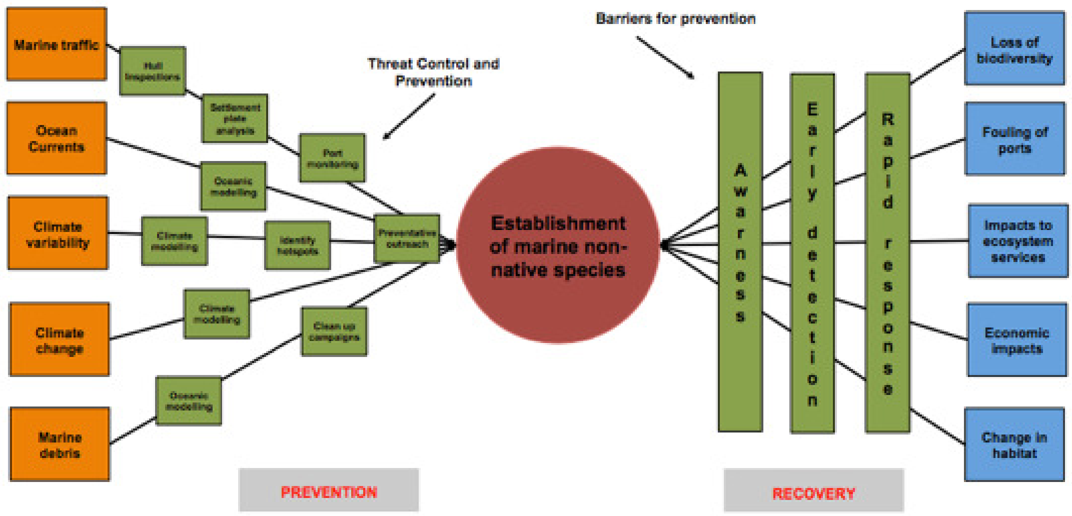


Figure 6.2: BowTie diagram illustrating the establishment of non-native species

6.6 Discussion

This chapter describes the Ecuadorian governments National Plan for Good Living 2013-2017 and explains how the research carried out for this thesis falls within the Ecuadorian governments environmental policies. One of the Ecuadorian government's priorities is the management of invasive species and the protection of biodiversity. During the research for this thesis, two documents were written to improve the biosecurity of the GMR and for decision makers to have risk assessment and management tools in order to be able to mitigate marine non-native species introductions to the GMR.

The action plan to minimize risks of marine invasive species introductions into the GMR describes four main questions that local decision makers and bioinvasion experts think are a priority to prevent marine non-native species arriving to the GMR. Interestingly, the research conducted for this thesis has already begun to address and answer several of the questions stated in the action plan, therefore already being able to give recommendations to the managers of the GMR.

The management strategy suggested and implemented for the nine marine non-native species that are present in the GMR at this time is to place them on a priority 'watch list'. Through this research, the CDF, the DPNG and ABG have established monitoring programs in order to keep an eye on these species spreading or causing severe impacts to the GMR. Additionally part of the research for this thesis was to raise awareness throughout the local institutions and the community, several capacity building workshops (Appendix I) where organised and presentations to 500 Galapagos naturalist guides where conducted in order to promote the 'watch list' and ask for their assistance as they are the ones navigating round the archipelago on a weekly bases and can report any noticeable changes.

This priority 'watch list' allow managers to have all the information of how the non-native species are behaving and are aware of the risks of these species proliferating. Additionally, managers can have a rapid response plan that can be implemented in the case one of these non-natives changed its current behaviour.

A biosecurity plan using a ranking risk analysis was described in this chapter to illustrate a method of managing hulls and port structures to prevent the introduction of non-native species to the GMR. This kind of method is very useful for categorizing risks in a fast and efficient manner when there is a specific risk that needs managed, as illustrated through the 'Copa Galapagos' example. This type of risk analysis is recommended for all regattas prior to their arrival in the GMR and any type of similar event that might take place.

Another risk assessment tool described in this chapter is the Bow-Tie method. This method is excellent to portray the management issues as a whole. It allows for several different risks to be illustrated at once and shows clearly what is at risk. The Bow-Tie risk assessment created for this thesis uses the questions raised in the action plan (Keith & Toral, 2015) to illustrate the risks of how marine no-natives species could be transported to the GMR (Chapters 4 and 5) Additionally, it illustrates the core values that were discussed in Chapter 4 and how these could be lost and what barriers decision makers have to enforce in order to prevent the arrival of non-native species and to protect the core values from these problematic species. The interesting thing about the Bow-Tie method is that other risk assessments can be conducted for each individual risk, for example, the risk of marine traffic transporting biofouling organisms can be assessed further by using the species based analysis (Chapter 4), that one risk assessment would be one part of the Bow-Tie method.

One of the several interesting points the action plan (Keith & Toral, 2015) raised in question 3 - section 3.5 is creating an Emergency Operations Committeefor marine non-native species. It is suggested in this thesis that creating this committee must be considered a high priority for managers due to the fact that so many different institutions are involved in the protection of the GMR a core group should be designated specifically to prevent the introduction of marine non-native species to the GMR. This group should have a representative from each government institution involved with invasive species as well as a scientific representative. Creating this core group of experts designated to work in prevention and rapid response management strategies is a step in the right direction and is an idea that could be replicated in other islands in the region in order to form a network of groups working together for the prevention of marine non-native species being spread and introduced within the ETP region.

Chapter 7:

Conclusion

7.1 Introduction

This thesis has described a list of non-native species found in the GMR by 2015 and the impacts that these species could potentially have on the biodiversity, ecosystem services and health of the GMR as well as examining the risk of the arrival of high-risk non-native species through marine traffic, oceanic currents, marine debris, connectivity, escapes and climate variability. Additionally this thesis examines two different risk assessments and management strategies to facilitate the mitigation of marine non-natives species and provides recommendations to GMR managers.

7.2 Summary of research main findings and conclusions

The nine marine non-native species revealedduring the research for this thesis have generated the baseline for marine non-native species in the GMR. The results from the literature review on marine non-native species in the GMR and the results from the diving surveys carried out in the ports and around the archipelago matched, with the exception of *Schizoporella unicornis*, which was not found and this list was supplanted by the three new non-native species reported during 2015.

Several different methods were used when searching for marine non-native species to cover as many habitats as possible in order to find a larger range of non-native species. This approach worked positively and provided the six non-native species from the literature review as well as the discovery of *Amathia verticillatum* (McCann *et al.* 2015), *Botrylloides nigrum* and *Botrylloides pizoni*. However in order to positively identify the two ascidians, molecular biology was used.

The use of molecular biology had not been originally considered as part of this thesis because the marine laboratory in the CDRS does not have the technology or expertise needed to conduct these types of DNA tests as well as the high costs involved with these techniques. It was through collaboration with Dr Jim Carlton after the first international workshop on marine bioinvasions of tropical island ecosystems in the CDRS that samples taken in the GMR were sent to Dr Geller at the Moss Landing Marine Laboratories with permission from the DPNG.

The research for this thesis did not to rely on the use of molecular biology techniques to identify species as many of the non-native species identified were macro fauna that could be identified through identification guides and photographic identification by experts. However this research benefited from it, and the list of non-native species was extended due to the use of molecular biology and collaboration with international taxonomic experts, suggesting that in future research both molecular biology and taxonomic experts are key in order to continue identifying marine non-native species in the GMR, especially species that are harder to identify such as the ascidians and sponges.

The settlement plate pilot project started during this research is a perfect example of how the previously mentioned skills are crucial for the identification of the organisms growing on the plates. The results for these settlement plates will be collected in April 2016 after an identification workshop organised at CDRS is conducted with taxonomic experts from around the world (USA: James T. Carlton, Gregory M. Ruiz, Linda McCann, Jonathan B. Geller, Gretchen Lambert, Kristen Larson, Daniel Cleary; Canada: Dale Calder; Netherlands: Nicole de Voogd). The identification of species will be conducted using skills from the above-mentioned experts and molecular biology techniques in laboratories in the USA, the results are expected to provide new records for the GMR.

This thesis identified marine traffic as the greatest anthropogenic threat for the transport of marine non-native species to the GMR. The international and national marine traffic arriving to the GMR was analysed indicating Panama and Guayaquil (Ecuador) as the two hotspots for the translocation of non-native species. There are several potential high-risk species that could damage the marine ecosystems of the Galapagos Islands, and these were presented through the species based exposure analysis. The expansion of the Panama Canal potentially increases the risks of species being transported throughout the ETP. The Suez Canal is an example of how growth in transport and industry led this canal to be expanded. The Suez Canal is known to be one of the most powerful corridors for invasions of marine species worldwide (Galil *et al.* 2014) An example of a high-risk species for the GMR is the snowflake coral (*Carijoa riisei)* that has already been reported in continental Ecuador and the island of Malpelo, Colombia. This species is a well-known fouling organism that could easily be transported by the increasing marine traffic in the region.

Based on the 2013 data analysed there are 469 high-risk species for the GMR, and this list of species can increase in correlation to the increase of marine travel and the amount of marine traffic the GMR receives from different regions in the world. It is due to this risk that it is suggested in this thesis that tougher regulation and stricter quarantine protocols have to be put in place to increase the biosecurity of the GMR. It is necessary to increase the quarantine border control beyond the GMR. This thesis presents the idea of forming a network of biosecurity nodes throughout the ETP region. The first node would be created in the GMR through the ABG, and in order to form a network it is suggested that the other MPA's in the ETP are contacted, and they become nodes along with hotspot ports like Panama and Guayaquil. Each node would work as a quarantine control for the next node and visa-versa. By creating this initial network, the risk of non-native species translocation would decrease. The idea would be for each node to expand outwards towards another region, so the GMR could expand not only within the ETP but towards the French Polynesian islands, and they could expand towards New Zealand and Australia and Panama could expand towards Mexico and they could expand to the USA.

The Ecuadorian government is working hard to improve the cargo fleet and the quarantine controls for cargo ships as well as considering a purpose built cargo hub being constructed to aid the biosecurity needs of the Galapagos Islands. The cargo hub will centralize all the cargo in one place and then local vessels will be able to distribute the cargo within the islands. The advantages the cargo hub presents are (i) all cargo vessels will enter the hub meaning that there is no possibility of the cargo ships transporting non-native species to all the ports in the archipelago, (ii) the area surrounding the hub where the boats from continental Ecuador enter can be constantly inspected for non-native species and rapid response protocols can be activated immediately, and (iii) the local vessels that distribute the cargo can be inspected whilst the cargo boats are in the port of Guayaquil receiving cargo hence minimizing any type of inter-island species transport. The research conducted for this thesis supports the Ecuadorian government's plan of constructing a cargo hub in the GMR but strongly recommends that the site chosen for the hub is previously inspected by trained marine biologists and a baseline study has to be conducted to be able to have information of which species are there prior to the arrival of cargo ships.

In order to increase the biosecurity, even with the construction of a cargo hub in the GMR, it is essential that all cargo vessels be subjected to hull cleaning during the time the vessel is loading cargo in the port of Guayaquil. This not only prevents the vessel transporting non-native species to the GMR but also minimizes the need for constant inspections to be conducted by divers in unsafe conditions.

The marine traffic that navigates within the GMR was also examined in this thesis, which presented the different types of vessels that could act as a dispersal vectors within the GMR. The number of tourist vessels and the inter-island speedboats are two of the most concerning factors due to the amount of trips they make either between ports or throughout the tourist sites. The idea of using a hub-spoke network model for secondary dispersal has been discussed (Campbell *et al.* 2013; Azmi *et al.* 2015), and this thesis recommends a future study of this kind in order to be able to present to managers of the GMR the risks of increased mobility within the islands and the need for stricter biosecurity controls to be enforced. It is important to note that, by preventing the arrival of non-native species to the GMR from different regions in the world, the issue of non-native species dispersal within the island is minimized which is why extending quarantine border control and creating a network of biosecurity nodes is of high priority for the prevention of marine non-native species entering the GMR through marine traffic.

This thesis additionally identified the connectivity in the ETP and climate variability through ENSO events as high-risk natural vectors that can aid in the transport of non-native species to the GMR. Furthermore this thesis examined how natural processes enhanced by anthropogenic activity can also assist in the translocation of non-native species.

Earlier in this thesis oceanic islands were discussed and the way in which they are more prone to invasion by non-native species. The geographic isolation of the Galapagos Islands is a perfect example. Marine non-native species larvae being transported through the natural connectivity of the current systems in this region is a risk for the GMR.A key example is the lionfish (*Ptereois volitans*) that, if introduced to the ETP, its larvae could be dispersed through oceanic currents causing a huge impact on the marine ecosystems of the region.

The dispersal of larvae is just the beginning of the risks that the GMR faces, for when ENSO events take place in this region, several species cannot survive the increase in SST creating niche space for non-native species to colonise. Add to this the paucity of natural competitors and predators due to geographic isolation and a big window of opportunity is created for the establishment of marine non-native species that may cause devastating effects to the marine ecosystems in the GMR.

The creation of this bioclimatic window of opportunity or(open niche scenario) is the biggest risk the GMR faces when evaluating opportunities for marine non-native species to establish. Once the open niche is created marine non-native species can take advantage and settle, reproduce and spread much easier than under normal conditions. With an open niche scenario, it does not matter whether non-native species arrive through marine traffic, ocean connectivity, ENSO events, climate change or marine debris because the fact is that there is a higher risk of non-native species proliferating due to the already impacted ecosystem caused by an ENSO event.

The GMR and the risks associated with the arrival of marine non-native species have to be considered as a whole, as it is not a good management strategy to divide the risks of the introduction of non-native species by marine traffic and the natural arrival through oceanic currents or climate variability. This separation can lead to managers deciding to only provide management tools for the introduced non-native species and not for those that arrive naturally. This thesis presents a high-risk scenario for the GMR that managers have to consider when assessing the arrival of non-native species to the GMR.

The biggest risk the GMR faces is as mentioned above, the open niche scenario that can be caused by ENSO events and/or global climate change. Both these examples result in an increased SST that causes effects on the marine ecosystems in the region. It can be argued that ENSO events occur naturally and that global climate change can be attributed to anthropogenic elements. Therefore, does this mean that non-native species arrival associated with an ENSO event do not need any type of management? On the other hand, should non-native species that arrive due to global climate change have management strategies? This thesis does not argue that a clear separation of introduced and natural arrivals in several other places in the world is possible and comprehensible. However this thesis presents the complexity of the GMR scenario that not only suffers from geographic isolation but also experiences strong ENSO events and like everywhere on the planet, global climate change has to be considered as well.

Species distribution models using current environmental conditions were presented in this thesis for various non-native species as well as one future example using environmental data from 2100. It is clear that as SST rises due to global climate change, more species are going to be able to migrate to new regions whilst others might travel to colder waters or perish leaving open niches.

Therefore, due to the high-risk of an open niche scenario occurring in the GMR, a preventative management strategy is suggested considering all marine non-native species arrivals (anthropogenic and natural) as high-risk. Prevention, early detection and rapid response protocols have to be put in place in order to minimize the threat of non-native species on the marine ecosystems of the GMR.

Risk assessments are key in management strategies, and several different methods have been described throughout this thesis. It was mentioned previously in this section that the management of non-native species should be looked at as a whole. However, it is important to conduct risk assessments for each individual species threat in order to have a concise and clear picture of the entire risk. The Bow-Tie method was presented earlier in this thesis as a valuable strategic method for viewing all different risks related to the arrival and establishment of marine non-native species as a whole. This method is versatile and risks can be added or removed depending on the different pathways and risk scenarios as well as adding or removing barriers to help adapt to or mitigate the risk. It is suggested that GMR managers should adopt this method when calculating the risks of marine non-native species in the GMR and for planning management strategies for prevention, early detection and rapid response protocols.

The research for this thesis has allowed me to work with technicians from local institutions like the DPNG, ABG, Ecuadorian Navy and INOCAR helping them with monitoring techniques and establishing management protocols. It is essential for this type of research that science and management work together for the greater good. During the research for this thesis, one of the frustrating elements was the job rotation system that government institutions have in place, especially in the Ecuadorian Navy. A job position or placement lasts for two years and then someone else replaces that person. This can be frustrating when training technicians on monitoring protocols and that person gaining experience and then for it to be restarted after two years. For a good monitoring system to work it is important to have well-trained people, that improve the techniques over time, providing an enhanced monitoring system as time goes on. This thesis recommends that wherever possible it is important to maintain the same technicians where possible, to maintain institutional memory, in order ensure a strong biosecurity team.

As stated earlier in this section it is crucial and strategically important that the GMR forms a biosecurity committee, and it is key that each institution is represented by a well-trained advisor that can make educated decisions based on risk assessments conducted. This committee would be the first node of the suggested plan of forming a network of biosecurity nodes expanding throughout the ETP region. The importance of regional collaboration is key for preventing the arrival of marine non-native species.

7.3 Recommendations for future research

The research needs carried out for this thesis does not stop with this thesis. The monitoring techniques carried out in this research have to be continued in order for early detection and rapid response protocols to work. The pilot settlement plate pilot project is expected to provide new species records for the GMR. Settlement plates have only been deployed on the Island of Santa Cruz at this time, and I strongly recommend that settlement plates be deployed in all the docks of the populated islands, and in key sites around the archipelago as well as in the ports on continental Ecuador. In order for positive identification of organisms growing on the plates, taxonomic experts and molecular biology techniques should be invited to collaborate on this research. The analysis of the plates with those found in Panama (STRI) will allow researchers to compare the findings between the sites.

A strong ENSO event began in 2015 and is expected to last until the end of the summer 2016. A study of the impact caused by this climate event is important in future research on non-native species in the GMR. The identification of areas sensitive to climate variability can be investigated and a vulnerability map produced. The implementation of high-resolution methodology can be implemented in order to detect marine non-native species arrival more rapidly. Additionally monitoring sensitive sites over the course of the ENSO event and the shift back to normal condition could produce interesting results of habitat regeneration. Important sites to monitor would be the far northern islands of Darwin and Wolf where the largest abundance of corals are found in the archipelago. The mortality of corals has been extreme in previous ENSO events, therefore, it would be interesting to monitor any invasion taking place due to potential open niche scenarios.

During the research for this thesis, an oceanic circulation modelling component was considered and a cooperation agreement was signed between North Carolina State University (NCSU) the CDF, the University of Southampton and the University of Dundee. However, the extreme complexity of the modelling meant that the work was not completed until October 2014. Whilst, not an explicit objective, this was intended to extend the Australian CONNIE 2 ocean particle tracking model http://www.csiro.au/connie2/background/, from the western Pacific to the Galapagos/Tropical Eastern Pacific. There have been delays in rolling out new features of the freely accessible Marine Connectivity interface http://www.csiro.au/connie2/. The idea is that this model will eventually provide INOCAR with a decision support tool to forecast the rate of transport of marine non-native species larvae. The data is available and it would be valuable to continue this research in order to see this through to the envisaged endpoint.

Research should be done in collaboration with the Ecuadorian ballast water Task Force that initiated by the Ecuadorian government to establish management protocols for vessels arriving in the ports of continental Ecuador in order to minimize the spread of non-native species towards the GMR.

It is important to establish regional cooperation to minimize the negative impacts of non-native species to the ETP region. The creation of a regional biosecurity network to prevent future invasions by non-native marine species in the region is crucial. It is uncertain how non-native species will respond to climate change or climate variability now or in the future therefore it is important to establish prevention, early detection and rapid response protocols that can be used throughout the region.

7.4 Conclusion

The subject of marine non-native species necessarily requires research to be conducted on the broader mobility and environmental issues affecting the world today related to the biological threat that some species pose. For the Galapagos Islands and the conservation of the incredible marine realm that is the GMR, the prevention and management of non-native species arrival is critical in the preservation of biodiversity of the marine ecosystems.

An insight into the impacts marine non-native species can have on biodiversity, ecosystem services and the health of the GMR were evaluated and described in this thesis.Furthermore, the anthropogenic and natural vectors were examined and risk assessments were discussed with the open niche scenario presented as the biggest threat that the GMR faces when it comes to the arrival of non-native species. Management recommendations have been proposed and, the importance of further research on marine non-native species has been highlighted in order to safeguard the future biosecurity of the GMR.

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Appendix I

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Establishment of an effective biosecurity plan to prevent the introduction of invasive species to the Galapagos Islands - *Establecimiento de un sistema de bioseguridad eficaz para prevenir la introducción de especies invasoras a las Islas Galápagos.* WildAid, Part II, Guayaquil, Ecuador. (September, 2012).

Establishment of an effective biosecurity plan to prevent the introduction of invasive species to the Galapagos Islands - *Establecimiento de un sistema de bioseguridad eficaz para prevenir la introducción de especies invasoras a las Islas Galápagos.* WildAid, Part I, Guayaquil, Ecuador. (June 2012).

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Appendix II

Code	Name of site	Latitude	Longitude
DA01	Darwin Fondeadero Norte	1.68095	-92.001
DA02	Darwin Fondeadero Sur	1.68074	-91.9995
DA03	Arco Darwin	1.67363	-91.98928
DA04	Arrecife Escondido	1.6744	-91.99287
DA05	Arrecife Antiguo	1.67442	-91.992873
DA06	Darwin Fondeadero Pared	1.6812	-92.0066
DA07	Darwin Este	1.6779	-91.998
DA08	Darwin Sitio Desconocido (Di)	1.679587	-92.00337
ES01	Bahía Gardner Norte (1)	-1.34421	-89.6682
ES02	Cerro Colorado	-1.37844	-89.6236
ES03	Bajo Gardner	-1.34813	-89.6366
ES04	Bahía Gardner Sur	-1.3655	-89.6337
ES05	Punta Manzanillo	-1.34495	-89.701
ES06	Punta Cevallos	-1.39802	-89.6251
ES07	Punta Suarez Norte (1)	-1.35867	-89.7379
ES08	Bahía Punta Suarez (1)	-1.36712	-89.7459
ES09	Islote Tortuga Suroeste	-1.35267	-89.6489
ES10	Islote Tortuga Este	-1.35158	-89.6472
ES11	Bahía Gardner Norte (2)	-1.34534	-89.66467
ES12	Isla Gardner	-1.33901	-89.64402
ES13	Cerro Colorado Norte	-1.374	-89.6246
ES14	Islote Gardner Este	-1.3408	-89.636
ES15	Bahía Gardner Norte (3)	-1.34487	-89.67059
ES16	Punta Cevallos Sur	-1.4059	-89.6244
ES17	El Trompo - Punta Albatros (Di)	-1.4025	-89.6886
ES18	Bahía Gardner	-1.355782	-89.64816
ES19	Bahía Punta Suarez (2)	-1.369063	-89.74138
ES20	Bahía Punta Suarez (3)	-1.368093	-89.73892
ES21	Costa Norte Española	-1.3467	-89.68027
ES22	Islote Gardner Sur	-1.34735	-89.64473
ES23	Punta Cevallos Norte	-1.3836	-89.62041
ES24	Punta Suarez Norte (2)	-1.360233	-89.7386
ES25	Punta Suarez Sur	-1.379667	-89.73585
ES26	Punta Cevallos (2) (FR)	-1.39915	-89.62689

ES27	Punta Manzanillo (2)	-1.34658	-89.70095
ES28	Punta Manzanillo (3)	-1.34777	-89.7006
ES29	Punta Manzanillo (4)	-1.34683	-89.69818
ES30	Punta Manzanillo (1)	-1.34495	-89.701
FE01	Cabo Douglas Piedra Blanca	-0.3018	-91.6524
FE02	Cabo Douglas (2)	-0.30037	-91.6483
FE03	Punta Espinosa Norte (1)	-0.27079	-91.437
FE04	Punta Espinosa Norte (2)	-0.261942	-91.44458
FE05	Punta Espinosa Sur (1)	-0.27205	-91.435
FE06	Punta Espinosa Sur (2)	-0.2739	-91.4311
FE07	Punta Mangle (N)	-0.4372	-91.3876
FE08	Punta Mangle (S)	-0.45	-91.3847
FE09	Punta Priscila (1)	-0.3713	-91.3813
FE10	Punta Priscila (2)	-0.36996	-91.3799
FE11	Smurfs Punta Espinosa	-0.27111	-91.4368
FE12	Punta Espinosa Sur (3)	-0.27544	-91.4276
FE13	Punta Espinosa Norte (3)	-0.25915	-91.45712
FE14	Cabo Douglas Sur (2)	-0.3092	-91.6647
FE15	Cabo Douglas Fondeadero	-0.30119	-91.65047
FE16	Cabo Douglas Sur (1)	-0.3188	-91.6676
FE17	Cabo Douglas Este	-0.29838	-91.6244
FE18	Cabo Hammond	-0.47965	-91.60721
FE19	Fernandina Suroeste	-0.492	-91.55114
FE20	Cabo Hammond Norte	-0.448595	-91.62708
FE21	Costa Centro Oeste	-0.39143	-91.65234
FE22	Fernandina Sureste	-0.49838	-91.4584
FE23	Paraíso de Pedro	-0.33522	-91.64321
FE24	Cabo Douglas Sur (3)	-0.315	-91.668
FE25	Cabo Douglas Sur (4)	-0.326	-91.667
FE26	Islote Costa Oeste	-0.335667	-91.65775
FE27	Punta Mangle Norte	-0.424983	-91.3895
FE28	Punta Espinosa Fond (2)	-0.275	-91.441
FE29	Punta Espinosa Fond (1)	-0.2716	-91.4421
FE30	Costa Noroeste de Saliente 2.1 (FR)	-0.34637	-91.65285
FE31	Punta Espinosa Noreste 2.2 (FR)	-0.26178	-91.44709
FE32	South Central Coast 2.3 (FR)	-0.50708	-91.50806
FE33	Cabo douglas turismo (1)	-1	-90
FE34	Cabo douglas tourism (2)	-1	-90
FE35	Cabo douglas prot (1)	-1	-90
FE36	Cabo douglas prot(2)	-1	-90
FL01	Champion	-1.23552	-90.3865
FL02	Corona del Diablo Norte	-1.21579	-90.42287
FL03	Enderby	-1.23502	-90.3655
FL04	La Botella Chica	-1.28928	-90.4971

FL05	La Botella	-1.29029	-90.4989
FL06	Las Cuevas Norte	-1.25141	-90.3742
FL07	Las Cuevas Sur	-1.26277	-90.3581
FL08	Control Graciela	-1.23953	-90.40044
FL09	Punta Luz de Día	-1.23015	-90.4737
FL10	Los Barrancos	-1.2444	-90.4854
FL11	Roca KK	-1.23482	-90.4829
FL12	Corona del Diablo Sur	-1.21718	-90.42328
FL13	Punta Cormorán	-1.22564	-90.4195
FL14	Tres Cuevitas	-1.23515	-90.4084
FL15	Islote Caldwell	-1.3025	-90.3377
FL16	Islote Gardner	-1.3311	-90.3012
FL17	Punta Luz de Día Oeste	-1.22964	-90.46817
FL18	Punta Ayora Sur	-1.2852	-90.3576
FL19	Floreana Suroeste 1 (Di)	-1.3	-90.5048
FL20	Floreana Suroeste 2 (Di)	-1.3302	-90.50771
FL21	Champion Lobos	-1.23348	-90.38544
FL22	Corona Corazón	-1.216468	-90.42371
FL23	Frente Champion (1)	-1.242983	-90.39725
FL24	Frente Champion (2)	-1.244013	-90.39566
FL25	La Montura (1)	-1.30791	-90.50491
FL26	La Montura (2)	-1.309332	-90.5061
FL27	Las Cuevas N (2)	-1.24915	-90.37878
FL28	Punta Ayora	-1.277067	-90.35136
FL29	Punta Cormorán Norte (1)	-1.21996	-90.42551
FL30	Punta Cormorán Norte (2)	-1.220818	-90.42815
FL31	Champion (FR)	-1.23554	-90.38329
FL32	Corona del Diablo Centro (FR)	-1.21644	-90.42313
GE01	Bahía Darwin Pared Norte	0.31164	-89.9456
GE02	Bahía Darwin Pared Este	0.3045	-89.95016
GE03	Genovesa Protección Este	0.30032	-89.94461
GE04	Genovesa Protección Oeste	0.30678	-89.9681
GE05	Genovesa Fondeadero Norte (1)	0.34017	-89.96983
GE06	Genovesa Fondeadero Norte (2)	0.33531	-89.97502
GE07	Genovesa Protección Este (2)	0.299806	-89.95211
GE08	Genovesa Norte	0.34407	-89.96083
GE09	Genovesa Oeste (Di)	0.32	-89.98
GE10	Genovesa Noreste (Di)	0.3368	-89.93952
GE11	Caída Bahía Darwin Oeste	0.31265	-89.94804
GE12	Bahía Darwin Entrada Este	0.3001	-89.95464
GE13	Bahía Darwin Entrada Oeste	0.30883	-89.96292
GE14	Bahía Darwin Pared (1)	0.306233	-89.94587
GE15	Bahía Darwin Pared (2)	0.307483	-89.94523
GE16	Bahía Darwin Norte (FR)	0.31463	-89.95326
IS01	Cabo Marshall Norte (2)	-0.00726	-91.2157

IS02	Cabo Marshall Norte (1)	-0.00414	-91.217
IS03	Playa Negra (1)	-0.25458	-91.389
IS04	Playa Negra (2)	-0.24268	-91.3946
IS05	Playa Negra (3)	-0.22311	-91.3984
IS06	Tagus Pesca (1)	-0.30298	-91.3602
IS07	Tagus Pesca (2)	-0.31059	-91.3543
IS08	Caseta Png Norte (2)	-0.29752	-91.3591
IS09	Tagus Turismo (2)	-0.27315	-91.3671
IS10	Roca Redonda Ventos		-91.62377
IS11	Roca Redonda Norte		-91.6276
IS12	Tagus Pesca (3)	-0.31334	-91.3519
IS13	Islote Cowley (Cr‡ter)	-0.3831	-90.9632
IS14	Puerto Villamil Semillero (1)	-0.96854	-90.99034
IS15	Puerto Villamil Semillero (2)	-0.96587	-90.97242
IS16	Puerto Villamil Semillero (3)	-0.97	-90.97
IS17	Puerto Villamil Semillero (4)	-0.96019	-90.96879
IS18	Punta Moreno Pesca (1)	-0.69246	-91.32271
IS19	Punta Moreno Pesca (2)	-0.69066	-91.31796
IS20	Punta Moreno Prot (1)	-0.71585	-91.3404
IS21	Punta Moreno Prot (2)	-0.72589	-91.34984
IS22	Punta Moreno Turismo (1)	-0.70053	-91.33129
IS23	Punta Moreno Turismo (2)	-0.70266	-91.33129
IS24	Caleta Derick (1)	-0.62965	-91.09022
IS25	Caleta Derick (2)	-0.63164	-91.09059
IS26	Los Cañones Pesca (1)	-0.32864	-91.33796
IS27	Los Cañones Pesca (2)	-0.33099	-91.3378
IS28	Punta Vicente Roca Pesca (1)	-0.04116	-91.52752
IS29	Punta Vicente Roca Pesca (2)	-0.04037	-91.52193
IS30	Punta Vicente Roca Turismo (3)	-0.04991	-91.55064
IS31	Punta Vicente Roca Prot (2)	-0.04701	-91.54444
IS32	Punta Vicente Roca Turismo (1)	-0.0536	-91.55924
IS33	Punta Vicente Roca Turismo (2)	-0.05167	-91.5588
IS34	Caseta PNG (1)	-0.30223	-91.35976
IS35	Caseta PNG (2)	-0.31059	-91.3543
IS36	Caleta Tagus Turismo (1)	-0.26461	-91.37553
IS37	Caleta Tagus Turismo (2)	-0.26766	-91.37229
IS38	Playa Tortuga Negra (1)	-0.25808	-91.38719
IS39	Playa Tortuga Negra (2)	-0.26084	-91.38768
IS40	Punta Vicente Roca Prot (1)	-0.04991	-91.54678
IS41	Bahía de Los Perros	-0.78568	-91.43231
IS42	Bahía Urbina Sur	-0.41082	-91.23263
IS43	Cabo Marshall Norte (3)	-0.0115	-91.2132
IS44	Cabo Marshall Bahía (1)	-0.0171	-91.2027
IS45	Caleta Negra Norte (1)	-0.1824	-91.39422
IS46	Caleta Tagus Sur	-0.27145	-91.3703

IS47	Caleta Negra Norte (2)	-0.206317	-91.39294
IS48	Cuatro Hermanos	-0.8557	-90.7482
IS49	Norte del Radar	-0.866434	-91.50458
IS50	Caleta Iguana Este	-0.99454	-91.44541
IS51	Isla Tortuga	-1.00947	-90.88121
IS52	Punta Albermarle Sureste	-0.149367	-91.32616
IS53	Punta Albermarle	-0.167483	-91.33582
IS54	Punta Moreno Este	-0.6878	-91.2976
IS55	Puerto Fragata	-0.66762	-91.2082
IS56	Caseta PNG Norte	-0.291583	-91.36325
IS57	San Pedro	-1.04828	-91.21195
IS58	Bahía Urbina	-0.40286	-91.23393
IS59	Bajo Cerro Ballena (Di)	-0.83	-90.83
IS60	Cabo Rosa (Di)	-1.05	-91.18
IS61	Caleta Iguana Norte 2 (Di)	-0.974447	-91.44856
IS62	Islote Cuatro Hermanos Oeste (Di)	-0.84419	-90.81231
IS63	Isla Tortuga (Di)	-1.00629	-90.87316
IS64	Bahía Darwin Norte (Di)	-0.561195	-90.95442
IS65	Punta Alfaro (Di)	-0.42	-90.95
IS66	Roca Blanca (Di)	-0.55109	-90.85909
IS67	Bahía Cartago Norte	-0.561195	-90.95442
IS68	Bahía Cartago Sur (1)	-0.56548	-90.95535
IS69	Bahía Cartago Sur (2)	-0.57265	-90.95901
IS70	Bahía Elizabeth	-0.603	-91.083
IS71	Bahía Urbina (2)	-0.400033	-91.23292
IS72	Cabo Marshall Bahía (2)	-0.01694	-91.20502
IS73	Cabo Marshall Bahía (3)	-0.01792	-91.20808
IS74	Cabo Marshall Norte (4)	0	-91.22
IS75	Cabo Marshall Norte (5)	-0.00301	-91.21766
IS76	Caleta Alcedo	-0.285	-91.109
IS77	Caleta Iguana Norte (1)	-0.968818	-91.45095
IS78	Caleta Iguana Norte (3)	-0.978735	-91.45099
IS79	Costa Sureste (1)	-0.85539	-90.83875
IS80	Costa Sureste (2)	-0.85693	-90.83816
IS81	El Muñeco	-0.015987	-91.5684
IS82	Isabela Noroeste / Piedra Blanca	-0.137417	-91.38329
IS83	Las Marielas	-0.5996	-91.09059
IS84	Puerto Bravo	-0.041084	-91.41446
IS85	Punta Albermarle (2)	-0.16243	-91.33272
IS86	Punta García	-0.30284	-91.09649
IS87	Punta Moreno Bahía	-0.71	-91.33
IS88	Caleta Tagus Bahía (FR)	-0.26271	-91.37143
IS89	Punta Vicente Roca Cueva (FR)	-0.04847	-91.55604
IS90	Punta Vicente Roca Sur (FR)	-0.03987	-91.52959

MA01	Roca Espejo	0.31283	-90.40129
MA02	Islote Espejo	0.30936	-90.40312
MA03	Punta Calle Oeste	0.28602	-90.50151
MA04	Punta Calle Este	0.2821	-90.49147
MA05	Roca Espejo Norte	0.314	-90.398
MA06	Marchena Norte (Di)	0.39	-90.49
MA07	Puerto Vélez (Di)	0.37197	-90.44769
MA08	Punta Montalvo 2 (Di)	0.38341	-90.45775
MA09	El Finado	0.315	-90.5423
MA10	El Finado Sur/ Piedras Blancas	0.3075	-90.5371
MA11	Playa del Muerto (El Finado)	0.3177	-90.5422
MA12	Punta Calle Este (2)	0.277675	-90.4836
MA13	Punta Espejo Sur (1)	0.2959	-90.4152
MA14	Punta Espejo Sur (2)	0.3028	-90.41064
MA15	Punta Montalvo (1)	0.38787	-90.47004
PI01	Punta Nerus Este (2)	0.63833	-90.75919
PI02	Pinta Este (2)	0.606533	-90.73805
PI03	Punta Nerus Este (1)	0.64143	-90.76593
PI04	Punta Nerus Oeste (1)	0.6377	-90.78458
PI05	Punta Nerus Oeste (2)	0.64435	-90.77442
PI06	Pinta Este (1)	0.62009	-90.74806
PI07	Cabo Ibetson (Di)	0.54438	-90.72117
PI08	Cabo Chalmers (Di)	0.55144	-90.77958
PI09	Pinta Este (3)	0.6249	-90.7538
PI10	Pinta Este (4)	0.625983	-90.75478
PI11	Pinta Este (5)	0.621533	-90.74813
PI12	Pinta Este (6)	0.627683	-90.75681
PI13	Pinta Norte	0.641633	-90.77033
PI14	Nerus M2K (FR)	0.64497	-90.77953
PI15	Sureste Pozada (FR)	0.54279	-90.73097
PZ01	Islote Onan	-0.600177	-90.65246
PZ02	Pinzón Noroeste	-0.589791	-90.67915
PZ03	Islote Dumb	-0.603167	-90.68868
PZ04	Pinzón Oeste	-0.591033	-90.68373
RA01	Rábida Fondeadero	-0.404	-90.7031
RA02	Rábida Noroeste	-0.4022	-90.7165
RA03	Rábida Este	-0.40516	-90.7011
RA04	Rábida Norte	-0.3969	-90.70405
SA01	Roca Don Ferdi	-0.3748	-90.5787
SA02	Albany	-0.1742	-90.8454
SA03	Caleta Bucanero Pared	-0.16455	-90.82963
SA04	Roca Cousins	-0.23645	-90.57447
SA05	Santiago Noreste (1)	-0.23095	-90.58803
SA06	Santiago Noreste (2)	-0.23551	-90.58061
SA07	Bartolomé	-0.27971	-90.54489

SA08	El Muerto	-0.29786	-90.55091
SA09	Bahía Sullivan	-0.28115	-90.56861
SA10	Puerto Nuevo Oeste	-0.3345	-90.819
SA11	Bucanero Sur	-0.17237	-90.83614
SA12	Puerto Nuevo Este	-0.3383	-90.8094
SA13	Rocas Beagle	-0.41248	-90.63001
SA14	Santiago Sur (Prot)	-0.3763	-90.6018
SA15	Santiago Sur (Pesca)	-0.366	-90.6551
SA16	Cousins Norte	-0.23459	-90.57501
SA17	Rocas Bainbridge(Di)	-0.346233	-90.56171
SA18	Albany Sur (1)	-0.172333	-90.84402
SA19	Albany Sur (2)	-0.175094	-90.84749
SA20	Bartolomé Este	-0.286017	-90.54028
SA21	Sombrero Chino	-0.368812	-90.57959
SA22	Bartolomé Sur	-0.289917	-90.54805
SA23	El Monje / Piedra Blanca	-0.16752	-90.82772
SA24	Islote Mao	-0.157343	-90.82052
SA25	Poza de Los Azules	-0.355	-90.674
SA26	Puerto Nuevo	-0.275372	-90.85088
SA27	Punta Baquerizo	-0.27027	-90.8598
SA28	Roca Bucanero	-0.154959	-90.81998
SA29	Salt Port	-0.276	-90.862
SA30	Santiago Noreste (3)	-0.245174	-90.5781
SA31	Espumilla (FR)	-0.19627	-90.8337
SA32	Rocas Bainbridge F1 (FR)	-0.35266	-90.56608
SA33	Canal Bartolomé (FR)	-0.29248	-90.56105
SA34	Roca Cousins (FR)	-0.23558	-90.57451
SB01	Cerro Mundo	-0.86933	-89.5829
SB02	Islote Pitt	-0.7027	-89.2456
SB03	León Dormido Sur	-0.779268	-89.51892
SB04	Punta Pitt Norte	-0.69013	-89.269
SB05	Punta Pitt Este	-0.71144	-89.2438
SB06	Isla Lobos (1)	-0.8539	-89.5686
SB07	Galapaguero	-0.68879	-89.2991
SB08	León Dormido Pared	-0.77809	-89.5179
SB09	Caleta Tortuga Norte	-0.6982	-89.3695
SB10	Caleta Tortuga Sur	-0.7053	-89.3769
SB11	Five Fingers	-0.856536	-89.62773
SB12	León Dormido Oeste	-0.776886	-89.52142
SB13	Punta Pitt Oeste	-0.6915	-89.2589
SB14	Punta Pitt (Di)	-0.69976	-89.2506
SB15	Punta Pitt Lanchón (Di)	-0.71165	-89.24767
SB16	Islote Pitt Norte (Di)	-0.7021	-89.24815
SB17	Roca Ballena (Di)	-0.94891	-89.59193
SB18	20 Varas (1)	-0.943875	-89.57839

SB19	20 Varas (2)	-0.944888	-89.57592
SB20	Bahía Hobbs (1)	-0.701145	-89.28496
SB21	Bahía Hobbs (2)	-0.700733	-89.28374
SB22	Bahía Hobbs (3)	-0.70242	-89.28283
SB23	Chorros de Agua Dulce (1)	-0.93845	-89.47698
SB24	Chorros de Agua Dulce (2)	-0.938338	-89.47028
SB25	Isla Lobos (2)	-0.854675	-89.56938
SB26	Islote Pitt Sur	-0.7038	-89.24802
SB27	Las Negritas	-0.9439	-89.578
SB28	Punta Pitt Este (1)	-0.712572	-89.24261
SB29	Punta Pitt Este (2)	-0.712572	-89.24261
SB30	Punta Pitt Este (3)	-0.712637	-89.24141
SC01	Punta Carrión	-0.4823	-90.2501
SC02	El Planchón (1)	-0.5026	-90.4593
SC03	El Planchón (2)	-0.5052	-90.4373
SC04	Venecia	-0.5125	-90.4765
SC05	Guy Fawkes Este	-0.4987	-90.5162
SC06	Guy Fawkes Oeste	-0.51402	-90.5269
SC07	Islote Edén	-0.555017	-90.53722
SC08	Baltra Este	-0.4143	-90.27
SC09	Barranco Ayora	-0.74767	-90.27228
SC10	Daphne Mayor Suroeste	-0.43	-90.3696
SC11	Daphne Mayor Oeste	-0.4191	-90.3775
SC12	Daphne Barranco	-0.42156	-90.3697
SC13	Conway Norte	-0.53433	-90.52043
SC14	La Fe	-0.75501	-90.43644
SC15	Los Corales	-0.7725	-90.38269
SC16	Plazas Norte	-0.5777	-90.1565
SC17	Roca Sin Nombre	-0.66964	-90.58757
SC18	Seymour Norte	-0.3996	-90.2737
SC19	Conway Sur	-0.55792	-90.52905
SC20	Bahía Academia (Di)	-0.75	-90.3
SC21	Bahía Conway (Di)	-0.54087	-90.51602
SC22	Baltra Noroeste (Di)	-0.43	-90.29
SC23	Baltra Norte (Di)	-0.41305	-90.28975
SC24	Baltra Oeste (Di)	-0.46	-90.3
SC25	Capitanía (Di)	-0.74783	-90.31137
SC26	El Garrapatero (Di)	-0.7	-90.22
SC27	Cerro Gallina	-0.7446	-90.4547
SC28	Palmitas Sur	-0.68	-90.54
SC29	Rocas Gordon Pared	-0.565633	-90.1426
SC30	Rocas Gordon Sur	-0.5674	-90.1445
SC31	Seymour Norte (Este)	-0.391617	-90.27395
SC32	Seymour Norte (Sur)	-0.3995	-90.28623
SC33	Baltra Noreste (FR)	-0.41204	-90.28216

SC34	Bahía Conway 1 (FR)	-0.54696	-90.51362
SC35	Bahía Conway 2 (FR)	-0.55127	-90.51671
SC36	Bahía Conway 3 (FR)	-0.55729	-90.52085
SC37	Bajo Atras Camaño (FR)	-0.77192	-90.2833
SC38	Camaño (FR)	-0.75845	-90.2729
SC39	Caleta Robinson (FR)	-0.49838	-90.24623
SC40	Daphne Menor (FR)	-0.39438	-90.35351
SC41	El Garrapatero	-0.6982	-90.22102
SC42	El Garrapatero C	-0.7018	-90.21958
SC43	Sur Islote Edén (FR)	-0.56281	-90.53833
SC44	Bahía Academia (2)	-0.75159	-90.30625
SC45	Bahía Academia (3)	-0.75491	-90.30561
SC46	Bahía Academia (1)	-0.74628	-90.30285
SC47	Bahía Conway	-0.54183	-90.51345
SF01	Roca del Pingüino	-0.80508	-90.08719
SF02	Afuera Bahía Turismo	-0.80301	-90.03709
SF03	Dinamarca	-0.7986	-90.0763
SF04	Frente a Fondeadero (FR)	-0.80195	-90.03974
WO01	Wolf Corales (1)	1.38696	-91.8164
WO02	Wolf Corales (2)	1.387	-91.8166
WO03	Wolf Colonia de Lobos Norte	1.38374	-91.8117
WO04	Wolf Colonia de Lobos Sur	1.38318	-91.8111
WO05	Wolf Fondeadero (1)	1.37867	-91.8194
WO06	Wolf Fondeadero (2)	1.37978	-91.8183
WO07	Wolf Cavernas	1.375233	-91.81609
WO08	Wolf Corales (3)	1.385067	-91.81416
WO09	Wolf Corales (4)	1.3887	-91.81783
WO10	Wolf Sureste (1)	1.379667	-91.81181
WO11	Wolf Corales (5)	1.389383	-91.81731
WO12	Wolf Sitio Desconocido (Di)	1.38199	-91.81548
WO13	Wolf Norte (Di)	1.39151	-91.82097
WO14	Wolf Sureste (2)	1.378993	-91.81224

Appendix III

* cells with (-) means non-native species were not observed, cells marked with (X) means that site was not surveyed that year

Site	Latitude	Longitude	2012	2013	2014	2015
Bahía Gardner Norte (1)	-1.344210	-89.668200	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha
Cerro Colorado	-1.378440	-89.623600	-	-	-	-
Islote Tortuga Este	-1.351580	-89.647200	-	-	-	-
Bajo Gardner	-1.348130	-89.636600	-	-	-	-
Bahía Gardner Norte (2)	-1.345340	-89.664670	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha
Isla Gardner	-1.339010	-89.644020	Bugula neritina	Bugula neritina	Bugula neritina	Bugula neritina
Las Cuevas Sur	-1.262770	-90.358100	-	-	-	-
Corona del Diablo Sur	-1.217180	-90.423280	-	-	-	-
Tres Cuevitas	-1.235150	-90.408400	-	-	-	-
Champion	-1.235520	-90.386500	-	-	-	-
Corona del Diablo Norte	-1.215790	-90.422870	-	-	-	-
Punta Cormorán	-1.225640	-90.419500	-	-	-	-

La Botella	-1.290290	-90.498900	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha
Punta Luz de Día	-1.230150	-90.473700	-	-	-	-
Los Barrancos	-1.244400	-90.485400	-	-	-	-
Punta Luz de Día Oeste	-1.229640	-90.468170	-	-	-	-
Roca Cousins	-0.236450	-90.574470	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha
Santiago Noreste (1)	-0.230950	-90.588030	-	-	-	-
El Muerto	-0.297860	-90.550910	-	-	-	-
Santiago Noreste (2)	-0.235510	-90.580610	-	-	-	-
Bartolomé	-0.279710	-90.544890	-	-	-	-
Bahía Sullivan	-0.281150	-90.568610	-	-	-	-
Cabo Marshall Norte (3)	-0.011500	-91.213200	-	-	-	-
Cuatro hermanos-islote este	-0.848000	-90.749000	-	-	-	-
Rocas Beagle	-0.412480	-90.630010	-	-	-	-
Guy Fawkes	-0.499000	-90.513000	-	-	-	-
León Dormido Sur	-0.779268	-89.518920	-	-	-	-
León Dormido Pared	-0.778090	-89.517900	Bugula neritina	Bugula neritina	Bugula neritina	Bugula neritina
Five Fingers	-0.856536	-89.627730	-	-	-	-
Espumilla	0.3028	-90.41064	X	Cardisoma crassum	Cardisoma crassum	Cardisoma crassum
Roca sin nombre	-0.670231	-90.586085				

Pinzon	-0.589791	-90.67915	Bugula neritina	Bugula neritina	Bugula neritina	Bugula neritina
Bahia Cartago (1)	-0.19627	-90.8337	X	Caulerpa racemosa, Cardisoma crassum	Caulerpa racemosa, Cardisoma crassum	X
Caleta Iguana	-0.976990	-91.447040	Asparagopsis taxiformis	Asparagopsis taxiformis	Asparagopsis taxiformis	Asparagopsis taxiformis
Puerto Pajas	-0.755020	-91.374160	-	-	-	-
Las Marielas	-0.599010	-91.091270	X	Asparagopsis taxiformis	Asparagopsis taxiformis	Asparagopsis taxiformis
Punta Moreno Prot (2)	-0.725890	-91.349840				
Punta Moreno Turismo (2)	-0.702660	-91.331290	Asparagopsis taxiformis, Caulerpa racemosa	Asparagopsis taxiformis, Caulerpa racemosa	Asparagopsis taxiformis, Caulerpa racemosa	Asparagopsis taxiformis, Caulerpa racemosa
Punta Moreno Prot (1)	-0.715850	-91.340400	-	-	-	-
Punta Moreno Turismo (1)	-0.700530	-91.331290	-	-	-	-
Punta Priscila (2)	-0.369960	-91.379900	-	-	-	-
Punta Moreno Pesca (2)	-0.690660	-91.317960	-	-	-	-
Los Cañones Pesca (2)	-0.330990	-91.337800	-	-	-	-
Los Cañones Pesca (1)	-0.328640	-91.337960	-	-	-	-
Punta Moreno Pesca (1)	-0.692460	-91.322710	-	-	-	-
Punta Priscila (1)	-0.371300	-91.381300	-	-	-	-
Caseta PNG (1)	-0.302230	-91.359760	-	-	-	-
Caleta Tagus Turismo (1)	-0.264610	-91.375530	-	-	-	-
Playa Tortuga Negra (1)	-0.258080	-91.387190	-	-	-	-

Caseta PNG (2)	-0.310590	-91.354300	-	-	-	-
Caleta Tagus Turismo (2)	-0.267660	-91.372290	Pennaria disticha	Pennaria disticha	Pennaria disticha	Pennaria disticha
Playa Tortuga Negra (2)	-0.260840	-91.387680	-	-	-	-
Cabo Douglas Piedra Blanca	-0.301800	-91.652400	-	-	-	-
Punta Espinosa Norte (2)	-0.261942	-91.444580	-	-	-	-
Punta Espinosa Sur (2)	-0.273900	-91.431100	-	-	-	-
Punta Espinosa Norte (1)	-0.270790	-91.437000	-	-	-	-
Punta Espinosa Sur (1)	-0.272050	-91.435000	-	-	-	-
Puerto Pajas	-0.755020	-91.374160	X	Caulerpa racemosa	Caulerpa racemosa	Caulerpa racemosa
Punta Vicente Roca Pesca (2)	-0.040370	-91.521930	-	-	-	-
Punta Vicente Roca Prot (2)	-0.047010	-91.544440	-	-	-	-
Punta Vicente Roca Turismo (1)	-0.053600	-91.559240	X	Bugula neritina	Bugula neritina	Bugula neritina
Punta Vicente Roca Pesca (1)	-0.041160	-91.527520	-	-	-	-
Punta Vicente Roca Turismo (2)	-0.051670	-91.558800	X	Bugula neritina	Bugula neritina	Bugula neritina
Punta Vicente Roca Prot (1)	-0.049910	-91.546780	-	-	-	-
Wolf Corales (2)	1.387000	-91.816600	Pennaria disticha, Bugula neretina	Pennaria disticha, Bugula neretina	Pennaria disticha, Bugula neretina	X
Wolf Fondeadero (2)	1.379780	-91.818300	Pennaria disticha	Pennaria disticha	Pennaria disticha	X

Wolf Corales (1)	1.386960	-91.816400	Pennaria disticha, Bugula neritina	Pennaria disticha, Bugula neritina	Pennaria disticha, Bugula neritina	X
Wolf Fondeadero (1)	1.378670	-91.819400	Pennaria disticha	Pennaria disticha	Pennaria disticha	X
Wolf Colonia de Lobos Sur	1.383180	-91.811100	Asparagopsis taxiformis	Asparagopsis taxiformis	Asparagopsis taxiformis	X
Wolf Colonia de Lobos Norte	1.383740	-91.811700	-	-	-	-
Wolf Corales (2)	1.387000	-91.816600	X	Acanthaster planci, Penaria disticha, Bugula neritina	Acanthaster planci, Penaria disticha, Bugula neritina	X
Wolf Colonia de Lobos Sur	1.383180	-91.811100	-	-	-	-
Derrumbe	1.373280	-91.812810	-	-	-	-
Arco Darwin(1)	1.673630	-91.989280	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha	X
Darwin Fondeadero Norte	1.680950	-92.001000	-	-	-	-
Darwin Fondeadero Sur	1.680740	-91.999500	-	-	-	-
Arrecife Escondido	1.674400	-91.992870	Pennaria disticha	Pennaria disticha	Pennaria disticha	X
Pinta(1)			-	-	-	-
Pinta (2)			Bugula neritina	Bugula neritina	Bugula neritina	-
Arrecife Antiguo	1.674420	-91.992873	-	-	-	-

Islote Espejo	0.309360	-90.403120	-	-	-	-
Punta Calle Este	0.282100	-90.491470	-	-	-	-
Roca Espejo	0.312830	-90.401290	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha	X
Punta Calle Oeste	0.286020	-90.501510	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha	Bugula neritina, Pennaria disticha	X
Bahía Darwin Pared Norte	0.311640	-89.945600	-	-	-	-
Genovesa Protección Oeste	0.306780	-89.968100	-	-	-	-
Genovesa Fondeadero Norte (2)	0.335310	-89.975020	-	-	-	-
Bahía Darwin Pared Norte	0.311640	-89.945600	-	-	-	-
Genovesa Protección Este	0.300320	-89.944610	-	-	-	-
Genovesa Fondeadero Norte (1)	0.340170	-89.969830	-	-	-	-
Puerto Ayora	-0.75491	-90.30561	Bugula neritina	Bugula neritina, Cardisoma crassum	Bugula neritina, Cardisoma crassum	Bugula neritina, Cardisoma crasum, Botryloides nigrum, Botryloides pizoni, Amathia vercitilata
Puerto baquerizo moreno	-0.900113	-89.611721	Asparagopsis taxiformis, Bugula	Asparagopsis taxiformis, Bugula	Asparagopsis taxiformis, Bugula	Asparagopsis taxiformis, Bugula

Puerto Villamil	-0.96854	-90.99034	X	Asparagopsis taxiformis, Pennaria disticha, Caulerpa racemosa, Cardisoma crassum	Asparagopsis taxiformis, Pennaria disticha, Caulerpa racemosa, Cardisoma crassum	Asparagopsis taxiformis, Pennaria disticha, Caulerpa racemosa, Cardisoma crassum
Puerto velasco Ibarra	-1.274876	-90.490329	Pennaria disticha, Bugula neritina	Pennaria disticha, Bugula neritina	Pennaria disticha, Bugula neritina	Pennaria disticha, Bugula neritina
Baltra	-0.436106	-90.284572	Bugula neritina	Bugula neritina	Bugula neritina	Bugula neritina
Punta espinoza poza 1	-0.259300	-91.463380	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha, Botrylloides nigrum
Punta Espinoza poza 2	-0.259300	-91.463380	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha

Punta Espinoza poza 3	0.157680	-91.368090	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha
Punta espinoza poza 4	-0.259300	-91.463380	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha	Caulerpa racemosa, Asparagopsis taxiformis, Pennaria disticha
Punta Albemarle	0.154480	-91.369740	Caulerpa racemosa	Caulerpa racemosa	Caulerpa racemosa	Caulerpa racemosa
Punta Albemarle- Poza 1	0.163810	-91.344600	Caulerpa racemosa	Caulerpa racemosa	Caulerpa racemosa	Caulerpa racemosa
Punta Albemarle-Poza 2	0.164170	-91.359310	Caulerpa racemosa	Caulerpa racemosa	Caulerpa racemosa	Caulerpa racemosa
Punta Albemarle- Poza 3	-0.759410	-90.305810	Caulerpa racemosa	Caulerpa racemosa	Caulerpa racemosa	Caulerpa racemosa
Pinta Albemarle- Poza 4	-0.759410	-90.305810	Caulerpa racemosa	Caulerpa racemosa	Caulerpa racemosa	Caulerpa racemosa
Punta Estrada	-0.749000	-90.262800	-	-	-	-
Punta Núñez	-0.764000	-90.342000	-	-	-	-

Tortuga Bay (Playa Mansa)	-0.764000	-90.342000	Caulerpa racemosa	Caulerpa racemosa	Caulerpa racemosa	Caulerpa racemosa, Amathia vercitilata
Puerto Chino	-0.926082	-89.429259	-	-	-	-
Las Tijeretas	-0.887852	-89.607479	-	-	-	-
Franklins Bay	-0.755372	-90.312608	X	X	X	Amathia vercitilata
Los tuneles	-1.051571	-91.169624	-	-	-	-
El Finado	0.315	-90.5423	X	Caulerpa racemosa	Caulerpa racemosa	Caulerpa racemosa
Bahia cartago	-0.19627	-90.8337	-	-	Caulerpa racemosa	-
Bahia Ballena	-0.813174	-90.827531	X	X	Caulerpa racemosa	Caulerpa racemosa
Venecia	-0.5125	-90.4765	X	X	Caulerpa racemosa	Caulerpa racemosa

Appendix IV

Phylum	Species	Proportion of vessels likely to have been exposed	Exposure Rank
Annelida/Oligochaeta	*Paranais frici*	0.880434783	H
Annelida/Oligochaeta	*Tubificoides brownae*	0.913043478	H
Annelida/Oligochaeta	*Tubificoides wasselli*	0.884057971	H
Annelida/Polychaeta	*Ceratonereis mirabilis*	0.887681159	H
Annelida/Polychaeta	*Cirrhatulus caribous (=Timarete caribous)*	0.865942029	H
Annelida/Polychaeta	*Dispio uncinata (casual)*	1	H
Annelida/Polychaeta	*Eumida sanguineum*	0.945652174	H
Annelida/Polychaeta	*Eunice antennata*	1	H
Annelida/Polychaeta	*Eusyllis kupfferi*	0.858695652	H
Annelida/Polychaeta	*Exogone breviantennata*	1	H
Annelida/Polychaeta	*Ficopomatus enigmaticus*	0.945652174	H
Annelida/Polychaeta	*Ficopomatus uschakovi*	1	H
Annelida/Polychaeta	*Glycera capitata*	0.938405797	H
Annelida/Polychaeta	*Heteromastus filiformis*	0.938405797	H
Annelida/Polychaeta	*Hobsonia floridana*	0.884057971	H
Annelida/Polychaeta	*Hydroides cruciger*	0.945652174	H
Annelida/Polychaeta	*Hydroides brachyacanthus*	0.945652174	H
Annelida/Polychaeta	*Hydroides dianthus*	0.905797101	H
Annelida/Polychaeta	*Hydroides diramphus*	0.894927536	H
Annelida/Polychaeta	*Hydroides elegans*	0.923913043	H
Annelida/Polychaeta	*Hydroides gairacensis*	1	H
Annelida/Polychaeta	*Hydroides mucronatus*	0.847826087	H
Annelida/Polychaeta	*Hydroides sanctaecrucis*	0.865942029	H
Annelida/Polychaeta	*Janua marioni (=Spirorbis marioni)*	0.996376812	H
Annelida/Polychaeta	*Janua pagenstecheri*	1	H
Annelida/Polychaeta	*Janua steueri*	0.869565217	H
Annelida/Polychaeta	*Leonnates decipiens*	0.869565217	H
Annelida/Polychaeta	*Linopherus canariensis*	0.858695652	H
Annelida/Polychaeta	*Marenzelleria neglecta*	0.880434783	H
Annelida/Polychaeta	*Marphysa disjuncta*	1	H
Annelida/Polychaeta	*Marphysa sanguinea*	0.942028986	H
Annelida/Polychaeta	*Myrianida pachycera*	0.884057971	H
Annelida/Polychaeta	*Neanthes arenaceodonta*	0.93115942	H

Annelida/Polychaeta	*Neodexiospira brasiliensis (=Janua (Dexiospira) brasiliensis)*	0.913043478	H
Annelida/Polychaeta	*Nereis jacksoni*	1	H
Annelida/Polychaeta	*Novafabricia infratorquata*	0.858695652	H
Annelida/Polychaeta	*Oenone fulgida*	0.876811594	H
Annelida/Polychaeta	*Onuphis eremita ocultata*	0.858695652	H
Annelida/Polychaeta	*Polydora colonia*	0.905797101	H
Annelida/Polychaeta	*Polydora cornuta*	0.934782609	H
Annelida/Polychaeta	*Polydora websteri*	0.902173913	H
Annelida/Polychaeta	*Pomatoleios kraussii*	0.938405797	H
Annelida/Polychaeta	*Prionospio pygmaea (=Apoprionospio pygmaea)*	0.894927536	H
Annelida/Polychaeta	*Sigambra tentaculata (=Ancistrosyllis tentaculata)*	1	H
Annelida/Polychaeta	*Spirobranchus tetraceros*	0.858695652	H
Annelida/Polychaeta	*Streblospio benedicti*	0.920289855	H
Annelida/Polychaeta	*Streblospio gynobranchiata*	0.858695652	H
Annelida/Polychaeta	*Syllis gracilis*	0.905797101	H
Annelida/Polychaeta	*Syllis pectinans*	0.942028986	H
Annelida/Polychaeta	*Thelepus setosus*	0.942028986	H
Annelida/Polychaeta	*Timarete punctata*	0.858695652	H
Annelida-Polychaeta	*Crucigera websteri*	1	H
Annelida-Polychaeta	*Dipolydora armata (=armarta)*	1	H
Annelida-Polychaeta	*Dipolydora giardi*	0.989130435	H
Annelida-Polychaeta	*Dipolydora socialis*	0.934782609	H
Bryozoa	*Celleporaria brunnea*	0.956521739	H
Bryozoa	*Celleporella carolinensis*	0.858695652	H
Bryozoa	*Crisia eburnea*	0.898550725	H
Bryozoa	*Electra monostachys*	1	H
Chlorophyta	*Caulerpa brachypus*	0.865942029	H
Chlorophyta	*Caulerpa mexicana*	0.876811594	H
Chlorophyta	*Caulerpa racemosa var. lamourouxii*	0.876811594	H
Chlorophyta	*Caulerpa scalpelliformis*	0.869565217	H
Chlorophyta	*Caulerpa serrulata*	1	H
Chlorophyta	*Caulerpa taxifolia*	0.894927536	H
Chlorophyta	*Chaetomorpha aerea*	1	H
Chlorophyta	*Chaetomorpha linum*	1	H
Chlorophyta	*Cladophora herpestica*	0.949275362	H
Chlorophyta	*Cladophora lehmanniana*	0.898550725	H

Chlorophyta	*Cladophora prolifera*	1	H
Chlorophyta	*Cladophora sericea*	0.945652174	H
Chlorophyta	*Cladophoropsis membranacea*	0.876811594	H
Chlorophyta	*Codium fragile (=C. f. tomentosoides)*	1	H
Chlorophyta	*Codium ovale*	0.855072464	H
Chlorophyta	*Codium taylorii*	0.858695652	H
Chlorophyta	*Derbesia marina*	1	H
Chlorophyta	*Dictyosphaeria cavernosa*	0.865942029	H
Chlorophyta	*Halimeda opuntia*	1	H
Chlorophyta	*Neomeris annulata*	1	H
Chlorophyta	*Rhizoclonium lubricum (=Lola lubrica)*	0.996376812	H
Chlorophyta	*Ulva clathrata (=Enteromorpha clathrata var. crinata)*	1	H
Chlorophyta	*Ulva compressa (=Enteromorpha compressa)*	1	H
Chlorophyta	*Ulva flexuosa*	1	H
Chlorophyta	*Ulva intestinalis (=Enteromorpha intestinalis)*	1	H
Chlorophyta	*Ulva lactuca*	1	H
Chlorophyta	*Ulva prolifera (=Enteromorpha prolifera)*	1	H
Chlorophyta	*Ulva reticulata*	1	H
Chlorophyta	*Ulva rigida*	1	H
Chlorophyta	*Ulva taeniata*	0.967391304	H
Chordata/Ascidiacea	*Ciona intestinalis*	1	H
Chordata/Ascidiacea	*Clavelina oblonga*	0.876811594	H
Chordata/Ascidiacea	*Corella minuta*	0.855072464	H
Chordata/Ascidiacea	*Didemnum perlucidum*	0.855072464	H
Chordata/Ascidiacea	*Didemnum psammathodes*	0.865942029	H
Chordata/Ascidiacea	*Diplosoma spongiforme*	0.887681159	H
Chordata/Ascidiacea	*Distaplia bermudensis*	0.858695652	H
Chordata/Ascidiacea	*Distaplia corolla*	0.876811594	H
Chordata/Ascidiacea	*Ecteinascidia styeloides*	0.865942029	H
Chordata/Ascidiacea	*Herdmania momus*	0.876811594	H
Chordata/Ascidiacea	*Herdmania pallida*	0.865942029	H
Chordata/Ascidiacea	*Lissoclinum fragile*	0.884057971	H
Chordata/Ascidiacea	*Microcosmus exasperatus*	0.876811594	H

Chordata/Ascidiacea	*Molgula ficus*	0.949275362	H
Chordata/Ascidiacea	*Molgula manhattensis*	0.927536232	H
Chordata/Ascidiacea	*Molgula robusta*	0.865942029	H
Chordata/Ascidiacea	*Perophora multiclathrata*	0.876811594	H
Chordata/Ascidiacea	*Phallusia nigra (=Ascidia nigra)*	0.865942029	H
Chordata/Ascidiacea	*Polyandrocarpa sagamiensis*	0.938405797	H
Chordata/Ascidiacea	*Polyandrocarpa zorritensis*	0.884057971	H
Chordata/Ascidiacea	*Polyclinum constellatum*	0.873188406	H
Chordata/Ascidiacea	*Pyura preaputialis (=Pyura stolonifera preaputialis)*	0.93115942	H
Chordata/Ascidiacea	*Rhodosoma turcicum*	0.876811594	H
Chordata/Ascidiacea	*Styela canopus*	0.942028986	H
Chordata/Ascidiacea	*Styela plicata*	0.905797101	H
Chordata/Ascidiacea	*Symplegma brakenhielmi*	0.876811594	H
Chordata/Ascidiacea	*Trididemnum cf. savignii*	0.876811594	H
Chordata/Ascidiacea	*Trididemnum orbiculatum*	0.865942029	H
Chordata/Ascidiaces	*Cystodytes dellechiajei*	1	H
Chordata/Ascidiaces	*Didemnum candidum*	1	H
Chordata/Ascidiaces	*Diplosoma listerianum*	1	H
Chordata/Osteichthyes	*Gobiosoma nudum*	1	H
Chordata/Osteichthyes	*Hypleurochilus aequipinnis*	1	H
Chordata/Osteichthyes	*Hypsoblennius invemar*	0.847826087	H
Chordata/Osteichthyes	*Lophogobius cyprinoides*	1	H
Chordata/Osteichthyes	*Lupinoblennius dispar*	1	H
Chordata/Osteichthyes	*Stathmonotus stahli*	0.894927536	H
Chrysophyta	*Chrysonephos lewisii*	0.865942029	H
Cnidaria/Anthozoa	*Carijoa riisei*	1	H
Cnidaria/Anthozoa	*Diadumene leucolena*	1	H
Cnidaria/Anthozoa	*Diadumene lineata*	0.942028986	H
Cnidaria/Anthozoa	*Nematostella vectensis*	0.913043478	H
Cnidaria/Anthozoa	*Oulactis muscosa*	0.858695652	H
Cnidaria/Anthozoa	*Tethocyathus cylindraceus*	0.858695652	H
Cnidaria/Anthozoa	*Tubastraea coccinea*	1	H
Cnidaria/Anthozoa	*Tubastraea micranthus*	0.865942029	H
Cnidaria/Anthozoa	*Tubastraea tagusensis*	0.920289855	H
Cnidaria/Hydrozoa	*Cirrholovenia tetranema*	0.858695652	H
Cnidaria/Hydrozoa	*Cladonema pacificum (=uchidai)*	0.938405797	H

Cnidaria/Hydrozoa	*Cladonema radiatum*	0.945652174	H
Cnidaria/Hydrozoa	*Clytia hemisphaerica*	1	H
Cnidaria/Hydrozoa	*Clytia hummelincki*	1	H
Cnidaria/Hydrozoa	*Clytia mccradyi*	0.858695652	H
Cnidaria/Hydrozoa	*Clytia noliformis*	1	H
Cnidaria/Hydrozoa	*Clytia paulensis*	0.916666667	H
Cnidaria/Hydrozoa	*Cordylophora caspia*	1	H
Cnidaria/Hydrozoa	*Coryne eximia (=Sarsia eximia)*	1	H
Cnidaria/Hydrozoa	*Coryne pusilla*	0.898550725	H
Cnidaria/Hydrozoa	*Diphasia digitalis*	0.858695652	H
Cnidaria/Hydrozoa	*Dynamena disticha (=Dynamena cornicina)*	1	H
Cnidaria/Hydrozoa	*Dynamena quadridentata*	0.869565217	H
Cnidaria/Hydrozoa	*Eleutheria dichotoma*	0.887681159	H
Cnidaria/Hydrozoa	*Eucheilota paradoxica*	0.887681159	H
Cnidaria/Hydrozoa	*Eudendrium capillare*	1	H
Cnidaria/Hydrozoa	*Eudendrium carneum*	0.942028986	H
Cnidaria/Hydrozoa	*Filellum serratum*	0.887681159	H
Cnidaria/Hydrozoa	*Garveia franciscana*	0.938405797	H
Cnidaria/Hydrozoa	*Gonothyraea loveni*	0.934782609	H
Cnidaria/Hydrozoa	*Halecium delicatulum*	0.942028986	H
Cnidaria/Hydrozoa	*Hartlaubella gelatinosa*	0.923913043	H
Cnidaria/Hydrozoa	*Lensia challengeri*	1	H
Cnidaria/Hydrozoa	*Macrorhynchia philippina*	0.869565217	H
Cnidaria/Hydrozoa	*Maeotias marginata*	0.927536232	H
Cnidaria/Hydrozoa	*Moerisia inkermanica (=Ostroumovia inkermanica)*	0.887681159	H
Cnidaria/Hydrozoa	*Nemopsis bachei*	0.894927536	H
Cnidaria/Hydrozoa	*Obelia bidentata*	0.93115942	H
Cnidaria/Hydrozoa	*Obelia dichotoma*	1	H
Cnidaria/Hydrozoa	*Pennaria disticha*	1	H
Cnidaria/Hydrozoa	*Phialella quadrata*	1	H
Cnidaria/Hydrozoa	*Pinauay crocea*	0.934782609	H
Cnidaria/Hydrozoa	*Plumularia setacea*	1	H
Cnidaria/Hydrozoa	*Sarsia tubulosa*	0.93115942	H
Cnidaria/Hydrozoa	*Scolionema suvaensis*	0.865942029	H
Cnidaria/Hydrozoa	*Sertularia marginata*	0.869565217	H
Cnidaria/Hydrozoa	*Sertularia thecocarpa*	0.858695652	H
Cnidaria/Hydrozoa	*Sertularia tongensis (=Sertularia stechowi, S. theocarpa)*	0.876811594	H
Cnidaria/Hydrozoa	*Trichydra pudica*	0.887681159	H

	(casual)		
Cnidaria/Hydrozoa	*Tridentata loculosa (=Sertularia ligulata)*	0.865942029	H
Cnidaria/Scyphozoa	*Phyllorhiza punctata*	0.894927536	H
Cnidaria/Scyphozoa	*Stomolophus meleagris (causal)*	1	H
Cnidaria/Scyphozoa	*Turritipsis dohrnii*	1	H
Cnidaria/Scyphozoa	*Turritopsis nutricula*	0.865942029	H
Crustacea/Amphipoda	*Caprella penantis*	1	H
Crustacea/Amphipoda	*Caprella scaura*	1	H
Crustacea/Amphipoda	*Chelura terebrans*	0.934782609	H
Crustacea/Amphipoda	*Cymadusa filosa*	0.869565217	H
Crustacea/Amphipoda	*Elasmopus pectenicrus*	0.898550725	H
Crustacea/Amphipoda	*Elasmopus rapax*	1	H
Crustacea/Amphipoda	*Eobrolgus spinosus*	0.884057971	H
Crustacea/Amphipoda	*Ericthonius brasiliensis*	1	H
Crustacea/Amphipoda	*Gammaropsis togoensis*	0.858695652	H
Crustacea/Amphipoda	*Gammarus tigrinus*	0.898550725	H
Crustacea/Amphipoda	*Jassa marmorata*	1	H
Crustacea/Amphipoda	*Jassa slatteryi*	0.989130435	H
Crustacea/Amphipoda	*Laticorophium baconi*	1	H
Crustacea/Amphipoda	*Melita nitida*	0.913043478	H
Crustacea/Amphipoda	*Monocorophium acherusicum*	0.945652174	H
Crustacea/Amphipoda	*Monocorophium insidiosum*	1	H
Crustacea/Amphipoda	*Monocorophium uenoi*	0.956521739	H
Crustacea/Amphipoda	*Paracaprella pusilla*	1	H
Crustacea/Amphipoda	*Paracaprella tenuis*	0.865942029	H
Crustacea/Amphipoda	*Paradexamine pacifica*	0.93115942	H
Crustacea/Amphipoda	*Podocerus brasiliensis*	0.884057971	H
Crustacea/Amphipoda	*Stenothoe gallensis*	0.913043478	H
Crustacea/Amphipoda	*Stenothoe valida*	1	H
Crustacea/Amphipoda	*Tropichelura insulae*	0.865942029	H
Crustacea/Cirripedia	*Chthamalus fragilis*	0.865942029	H
Crustacea/Cirripedia	*Chthamalus proteus*	0.855072464	H
Crustacea/Cirripedia	*Concavus concavus species group (=Balanus concavus)*	0.938405797	H
Crustacea/Cirripedia	*Conchoderma virgatum*	1	H
Crustacea/Cirripedia	*Elminius kingii*	0.956521739	H
Crustacea/Cirripedia	*Fistulobalanus dentivarians*	0.967391304	H
Crustacea/Cirripedia	*Fistulobalanus pallidus*	1	H
Crustacea/Cirripedia	*Lepas (Anatifa) anatifera*	1	H
Crustacea/Cirripedia	*Lepas (Anatifa)*	1	H

	anserifera		
Crustacea/Cirripedia	*Lepas (Anatifa) hillii*	1	H
Crustacea/Cirripedia	*Loxothylacus panopaei*	0.865942029	H
Crustacea/Cirripedia	*Megabalanus coccopoma*	1	H
Crustacea/Cirripedia	*Megabalanus tintinnabulum*	0.898550725	H
Crustacea/Cirripedia	*Platylepas hexastylos*	0.916666667	H
Crustacea/Cirripedia	*Tesseropora atlantica*	0.847826087	H
Crustacea/Cirripedia	*Tesseropora wireni*	0.858695652	H
Crustacea/Cladocera	*Pleopis polyphemoides (introduced to Caspian)*	0.927536232	H
Crustacea/Decapoda	*Carcinus maenas*	1	H
Crustacea/Decapoda	*Charybdis hellerii*	1	H
Crustacea/Decapoda	*Dyspanopeus sayi*	0.905797101	H
Crustacea/Decapoda	*Eurypanopeus depressus*	0.865942029	H
Crustacea/Decapoda	*Eurypanopeus dissimilis*	1	H
Crustacea/Decapoda	*Goniopsis cruentata*	0.847826087	H
Crustacea/Decapoda	*Libinia dubia*	0.876811594	H
Crustacea/Decapoda	*Pachygrapsus gracilis*	0.876811594	H
Crustacea/Decapoda	*Pachygrapsus transversus*	0.887681159	H
Crustacea/Decapoda	*Panopeus lacustris*	0.855072464	H
Crustacea/Decapoda	*Panopeus rugosus*	1	H
Crustacea/Decapoda	*Percnon gibbesi*	1	H
Crustacea/Decapoda	*Petrolisthes armatus*	0.865942029	H
Crustacea/Decapoda	*Plagusia chabrus*	0.93115942	H
Crustacea/Decapoda	*Planes minutus*	0.894927536	H
Crustacea/Decapoda	*Pyromaia tuberculata*	0.949275362	H
Crustacea/Decapoda	*Rhithropanopeus harrisii*	0.927536232	H
Crustacea/Isopoda	*Cirolana harfordi*	0.949275362	H
Crustacea/Isopoda	*Eurylana arcuata*	0.949275362	H
Crustacea/Isopoda	*Iais californica*	0.949275362	H
Crustacea/Isopoda	*Iais floridana*	0.847826087	H
Crustacea/Isopoda	*Idotea metallica*	0.934782609	H
Crustacea/Isopoda	*Ligia exotica*	0.894927536	H
Crustacea/Isopoda	*Limnoria pfefferi*	0.858695652	H
Crustacea/Isopoda	*Limnoria quadripunctata*	0.905797101	H
Crustacea/Isopoda	*Limnoria saseboensis*	0.847826087	H
Crustacea/Isopoda	*Limnoria tripunctata*	0.942028986	H
Crustacea/Isopoda	*Paracerceis sculpta*	0.923913043	H
Crustacea/Isopoda	*Paradella dianae*	0.923913043	H
Crustacea/Isopoda	*Porcellio lamellatus lamellatus*	0.923913043	H
Crustacea/Isopoda	*Pseudosphaeroma campbellensis*	0.949275362	H

Crustacea/Isopoda	*Sphaeroma terebrans*	0.876811594	H
Crustacea/Isopoda	*Sphaeroma walkeri*	0.894927536	H
Crustacea/Isopoda	*Synidotea laevidorsalis*	0.920289855	H
Crustacea/Isopoda	*Uromunna sp. (=Munna reynoldsi)*	1	H
Crustacea/Ostracoda	*Kotoracythere inconspicua*	0.865942029	H
Crustacea/Tanaidacea	*Hexapleomera robusta*	1	H
Crustacea/Tanaidacea	*Leptochela dubia*	0.945652174	H
Crustacea/Tanaidacea	*Parapseudes pedispinis (=Parapseudes latifrons?)*	0.945652174	H
Crustacea/Tanaidacea	*Parazeuxo kurilensis (=Zeuxo maledivensis)*	0.847826087	H
Crustacea/Tanaidacea	*Sinelobus cf. stanfordi*	1	H
Crustacea/Tanaidacea	*Tanais dulongii*	0.916666667	H
Crustacea/Tanaidacea	*Zeuxo coralensis*	0.93115942	H
Ctenophora	*Vallicula multiformis*	0.873188406	H
Dinophyta	*Ostreopsis ovata*	0.865942029	H
Echinodermata/Echinoidea	*Eucidaris tribuloides*	0.858695652	H
Echinodermata/Echinoidea	*Tetrapygus niger*	0.920289855	H
Echinodermata/Ophiuroidea	*Ophiactis savignyi*	1	H
Ectoprocta	*Caulibugula dendrograpta*	0.865942029	H
Ectoprocta	*Celleporaria albirostris*	0.858695652	H
Ectoprocta	*Celleporaria pilaefera*	0.858695652	H
Ectoprocta	*Celleporella carolinensis*	0.858695652	H
Ectoprocta	*Celleporella hyalina*	0.996376812	H
Ectoprocta	*Conopeum reticulum*	1	H
Ectoprocta	*Conopeum seurati*	0.920289855	H
Ectoprocta	*Cryptosula pallasiana*	1	H
Ectoprocta	*Electra bengalensis*	1	H
Ectoprocta	*Electra tenella*	0.869565217	H
Ectoprocta	*Hippopodina feegensis*	0.876811594	H
Ectoprocta	*Hippopodina tahitiensis*	0.865942029	H
Ectoprocta	*Hippoporina indica*	1	H
Ectoprocta	*Hippothoa distans*	0.985507246	H
Ectoprocta	*Hippothoa divaricata*	1	H
Ectoprocta	*Jellyella eburnea*	0.865942029	H
Ectoprocta	*Jellyella tuberculata*	1	H
Ectoprocta	*Membraniporopsis tubigerum (=Conopeum tubigerum)*	0.858695652	H

Ectoprocta	*Microporella ciliata*	0.916666667	H
Ectoprocta	*Nolella stipata*	0.923913043	H
Ectoprocta	*Savignyella lafontii*	0.876811594	H
Ectoprocta	*Schizoporella serialis*	0.855072464	H
Ectoprocta	*Scrupocellaria bertholettii*	0.887681159	H
Ectoprocta	*Scrupocellaria scruposa*	0.992753623	H
Ectoprocta	*Sinoflustra annae*	1	H
Ectoprocta	*Smittina nitidissima (= Smittina malleolus)*	0.869565217	H
Ectoprocta	*Sundanella sibogae*	0.847826087	H
Ectoprocta	*Synnotum aegyptiacum*	0.894927536	H
Ectoprocta	*Victorella pavida*	0.938405797	H
Ectoprocta	*Watersipora arcuata*	0.956521739	H
Ectoprocta	*Watersipora subovoidea*	0.869565217	H
Ectoprocta	*Watersipora subtorquata*	0.923913043	H
Ectoprocta	*Zoobotryon verticillatum*	0.913043478	H
Entoprocta	*Loxomitra kefersteinii (=Loxosomella kefersteinii)*	0.898550725	H
Mollusca/Bivalvia	*Chama macerophylla*	0.855072464	H
Mollusca/Bivalvia	*Crassostrea gigas*	1	H
Mollusca/Bivalvia	*Geukensia demissa*	0.884057971	H
Mollusca/Bivalvia	*Hiatella arctica*	1	H
Mollusca/Bivalvia	*Hyotissa hyotis*	1	H
Mollusca/Bivalvia	*Ischadium recurvum*	0.884057971	H
Mollusca/Bivalvia	*Isognomon bicolor*	0.847826087	H
Mollusca/Bivalvia	*Lyrodus bipartitus*	0.858695652	H
Mollusca/Bivalvia	*Lyrodus massa*	0.858695652	H
Mollusca/Bivalvia	*Lyrodus mediolobatus*	0.865942029	H
Mollusca/Bivalvia	*Lyrodus pedicellatus*	0.942028986	H
Mollusca/Bivalvia	*Martesia cuneiformis*	1	H
Mollusca/Bivalvia	*Martesia striata*	0.865942029	H
Mollusca/Bivalvia	*Meretrix lusoria*	0.865942029	H
Mollusca/Bivalvia	*Mulinia cleryana (=Mulinia portoricensis)*	0.876811594	H
Mollusca/Bivalvia	*Musculista senhousia*	0.923913043	H
Mollusca/Bivalvia	*Mytella charruana*	1	H
Mollusca/Bivalvia	*Mytilopsis adamsi*	0.938405797	H
Mollusca/Bivalvia	*Mytilopsis leucophaeta*	0.90942029	H
Mollusca/Bivalvia	*Mytilopsis sallei*	0.876811594	H
Mollusca/Bivalvia	*Mytilopsis trautwineana*	1	H
Mollusca/Bivalvia	*Mytilus galloprovincialis*	0.996376812	H
Mollusca/Bivalvia	*Ostrea puelchana (=Ostrea chilensis)*	0.97826087	H
Mollusca/Bivalvia	*Perna canaliculata*	0.93115942	H

Mollusca/Bivalvia	*Perna perna*	0.869565217	H
Mollusca/Bivalvia	*Perna viridis*	0.865942029	H
Mollusca/Bivalvia	*Teredo bartschi*	0.913043478	H
Mollusca/Bivalvia	*Teredo clappi*	0.894927536	H
Mollusca/Bivalvia	*Teredo fulleri*	0.865942029	H
Mollusca/Bivalvia	*Teredo furcifera*	0.913043478	H
Mollusca/Bivalvia	*Teredo navalis*	0.945652174	H
Mollusca/Gastropoda	*Cenchritus muricatus (=Tectarius muricatus)*	0.865942029	H
Mollusca/Gastropoda	*Cerithium litteratum*	0.858695652	H
Mollusca/Gastropoda	*Creedonia succinea*	0.847826087	H
Mollusca/Gastropoda	*Crepidula convexa*	0.884057971	H
Mollusca/Gastropoda	*Crepidula onyx*	0.927536232	H
Mollusca/Gastropoda	*Crepidula plana*	0.884057971	H
Mollusca/Gastropoda	*Crepipatella dilatata*	0.956521739	H
Mollusca/Gastropoda	*Crucibulum spinosum*	0.945652174	H
Mollusca/Gastropoda	*Dendrodoris fumata*	0.949275362	H
Mollusca/Gastropoda	*Echinolittorina ziczac (=Littorina ziczac)*	1	H
Mollusca/Gastropoda	*Eupleura sulcidentata*	0.865942029	H
Mollusca/Gastropoda	*Favorinus auritulus*	0.865942029	H
Mollusca/Gastropoda	*Glossodoris sedna*	1	H
Mollusca/Gastropoda	*Littoraria angulifera (=Littorina scabra angulifera)*	1	H
Mollusca/Gastropoda	*Myosotella myosotis (=Phytia myosotis)*	1	H
Mollusca/Gastropoda	*Polycera hedgpethi*	0.989130435	H
Mollusca/Gastropoda	*Polycerella emertoni*	0.905797101	H
Mollusca/Gastropoda	*Pyrgophorus coronatus*	0.855072464	H
Mollusca/Gastropoda	*Sabia conica*	0.894927536	H
Mollusca/Gastropoda	*Siphonaria pectinata*	0.858695652	H
Mollusca/Gastropoda	*Stiliger fuscovitattus*	1	H
Mollusca/Gastropoda	*Stramonita (Thais) haemastoma floridana*	0.865942029	H
Mollusca/Gastropoda	*Syphonota geographica*	0.869565217	H
Mollusca/Gastropoda	*Tenellia adspersa*	0.938405797	H
Mollusca/Gastropoda	*Thecacera pennigera*	0.913043478	H
Phaeophyta	*Chnoospora minima*	1	H
Phaeophyta	*Cladosiphon zosterae*	1	H
Phaeophyta	*Cladostephus spongiosus*	0.934782609	H
Phaeophyta	*Colpomenia durvillei*	0.949275362	H
Phaeophyta	*Colpomenia sinuosa*	1	H
Phaeophyta	*Cystoseira compressa (= Cystoseira fimbriata)*	0.887681159	H
Phaeophyta	*Desmarestia viridis*	1	H

Phaeophyta	*Dictyota flabellata*	0.945652174	H
Phaeophyta	*Ectocarpus fasciculatus*	1	H
Phaeophyta	*Ectocarpus siliculosus*	1	H
Phaeophyta	*Endarachne binghamiae*	0.97826087	H
Phaeophyta	*Feldmannia indica*	1	H
Phaeophyta	*Feldmannia irregularis*	0.927536232	H
Phaeophyta	*Hincksia granulosa*	1	H
Phaeophyta	*Hincksia mitchelliae*	1	H
Phaeophyta	*Hincksia ovata*	1	H
Phaeophyta	*Hincksia sandriana*	0.938405797	H
Phaeophyta	*Hydroclathrus clathratus*	1	H
Phaeophyta	*Leathesia marina (=Leathesia difformis)*	1	H
Phaeophyta	*Macrocystis pyrifera*	0.985507246	H
Phaeophyta	*Myrionema strangulans*	0.938405797	H
Phaeophyta	*Padina antillarum*	0.869565217	H
Phaeophyta	*Padina boergesenii*	0.876811594	H
Phaeophyta	*Padina boryana*	0.876811594	H
Phaeophyta	*Pilayella littoralis*	1	H
Phaeophyta	*Punctaria latifolia*	0.938405797	H
Phaeophyta	*Punctaria tenuissima*	0.927536232	H
Phaeophyta	*Striaria attenuata*	1	H
Phoronida	*Phoronis hippocrepia*	1	H
Platyhelminthes	*Taenioplana teredini*	0.873188406	H
Platyhelminthes-Turbellaria	*Euplana gracilis*	0.905797101	H
Porifera	*Chalinula loosanoffi (=Haliclona loosanoffi)*	0.913043478	H
Porifera	*Cinachyrella alloclada*	0.847826087	H
Porifera	*Clathria prolifera (=Microciona prolifera)*	0.884057971	H
Porifera	*Cliona celata*	1	H
Porifera	*Desmapsamma anchorata*	0.847826087	H
Porifera	*Dictyonella hirta (=Hymeniacidon hirta)*	0.847826087	H
Porifera	*Dysidea avara*	0.905797101	H
Porifera	*Dysidea fragilis*	0.905797101	H
Porifera	*Halichindria coerulea*	0.873188406	H
Porifera	*Halichondria bowerbanki*	0.923913043	H
Porifera	*Halichondria melanadocia*	0.855072464	H
Porifera	*Halichondria panicea*	0.938405797	H
Porifera	*Leucosolenia botryoides*	0.898550725	H
Porifera	*Lissodendoryx*	0.934782609	H

	isodictyalis		
Porifera	*Mycale cecilia*	1	H
Porifera	*Mycale parishii (=Zygomycale parishii)*	1	H
Porifera	*Stelleta clarella*	0.938405797	H
Porifera	*Suberites aurantiacus (=S. zeteki)*	0.855072464	H
Porifera	*Tethya aurantium*	0.916666667	H
Protozoa/Ciliaphora	*Lagenophrys cochinensos*	0.876811594	H
Pycnogonida	*Endeis nodosa*	0.855072464	H
Pycnogonida	*Pigrogromitus timsanus*	1	H
Raphidophyta	*Fibrocapsa japonica*	0.916666667	H
Raphidophyta	*Heterosigma akashiwo (=Olisthodiscus luteus)*	0.923913043	H
Rhodophyta	*Centroceras clavulatum*	1	H
Rhodophyta	*Ceramium bisporum*	0.858695652	H
Rhodophyta	*Ceramium virgatum*	1	H
Rhodophyta	*Champia parvula*	1	H
Rhodophyta	*Chondria curvilineata*	0.858695652	H
Rhodophyta	*Chroodactylon ramosum*	0.938405797	H
Rhodophyta	*Colaconema caespitosum*	0.898550725	H
Rhodophyta	*Corallina officinalis*	1	H
Rhodophyta	*Dasya baillouviana*	0.927536232	H
Rhodophyta	*Erythrotrichia carnea*	1	H
Rhodophyta	*Eucheuma isiforme*	0.855072464	H
Rhodophyta	*Galaxaura rugosa*	0.869565217	H
Rhodophyta	*Gelidium pusillum*	1	H
Rhodophyta	*Gracilaria gracilis*	0.913043478	H
Rhodophyta	*Gracilaria tikvahiae*	0.873188406	H
Rhodophyta	*Gracilaria vermiculophylla*	0.916666667	H
Rhodophyta	*Gymnogongrus crenulatus*	0.934782609	H
Rhodophyta	*Gymnothamnion elegans*	0.923913043	H
Rhodophyta	*Herposiphonia parca*	0.865942029	H
Rhodophyta	*Hildenbrandia occidentalis*	0.97826087	H
Rhodophyta	*Hildenbrandia rubra*	1	H
Rhodophyta	*Hypnea anastomosans (=Hypnea esperi)*	0.967391304	H
Rhodophyta	*Hypnea cornuta*	0.876811594	H
Rhodophyta	*Hypnea musciformis*	0.923913043	H
Rhodophyta	*Hypnea spicifera*	0.949275362	H
Rhodophyta	*Hypnea spinella (=Hypnea cervicornis)*	0.876811594	H
Rhodophyta	*Hypnea valentiae*	1	H

Rhodophyta	*Kappaphycus alvarezii*	0.855072464	H
Rhodophyta	*Laurencia brongniartii*	0.887681159	H
Rhodophyta	*Laurencia caduciramulosa*	0.858695652	H
Rhodophyta	*Lomentaria orcadiensis*	0.898550725	H
Rhodophyta	*Mastocarpus papillatus*	0.938405797	H
Rhodophyta	*Monosporus indicus*	0.858695652	H
Rhodophyta	*Nemalion helminthoides*	0.920289855	H
Rhodophyta	*Neosiphonia harveyi (=Polysiphonia harveyi)*	0.938405797	H
Rhodophyta	*Plocamium secundatum*	0.942028986	H
Rhodophyta	*Polysiphonia atlantica*	1	H
Rhodophyta	*Polysiphonia breviarticulata*	0.887681159	H
Rhodophyta	*Polysiphonia denudata*	0.923913043	H
Rhodophyta	*Polysiphonia morrowii*	0.942028986	H
Rhodophyta	*Polysiphonia nigrescens*	0.905797101	H
Rhodophyta	*Polysiphonia paniculata*	0.949275362	H
Rhodophyta	*Polysiphonia sertularioides*	1	H
Rhodophyta	*Polysiphonia stricta*	0.981884058	H
Rhodophyta	*Polysiphonia subtilissima*	1	H
Rhodophyta	*Porphyra suborbiculata*	0.894927536	H
Rhodophyta	*Porphyra yezoensis*	0.905797101	H
Rhodophyta	*Prionitis lyallii*	0.938405797	H
Rhodophyta	*Schizymenia pacifica*	0.938405797	H
Rhodophyta	*Schottera nicaeensis*	0.971014493	H
Rhodophyta	*Schotterra nicaensis*	0.971014493	H
Rhodophyta	*Solieria filiformis*	0.916666667	H
Rhodophyta	*Spongoclonium caribaeum (=Pleonosporium caribaeum)*	0.894927536	H
Rhodophyta	*Wrangelia bicuspidata*	0.855072464	H

Appendix V

Value		Negligible to Very Low	Low	Moderate	High	Extreme
Habitat and habitat forming species	Information Gap				• Limited information is available on the identity and distribution of habitat types; limited information is available on the identity of habitat-forming species and their susceptibility to the NIS	
	Local area of value impacted	• No significant changes to habitat types observed;	• Localised affects on habitat in <10% of total habitat area;	• <30% of habitat area affected/replaced;	• <70% of habitat area affected/replaced;	• >70% of habitat area affected/replaced;
	Alteration of value	• no new habitat type observed in the invaded area; • populations of habitat forming species are not affected (<1% change);	• measurable changes to habitat types, new habitat type observed; • <10% reduction in population abundances of habitat forming species	• moderate changes to habitat types, new habitat type(s) observed, possible loss of at least one habitat type; • <30% reduction in population abundances of habitat forming species	• major changes to habitat types, new habitat types observed, loss of >30% pre-existing habitat types; • <70% reduction in population abundances of habitat forming species; • local/ecological extinction of at least one habitat forming species	• significant changes to habitat types, few pre-existing habitat types existing (>70% loss); • >70% reduction in population abundances of habitat forming species; • local/ecological extinction of more than one habitat forming species; global extinction of one habitat forming species
	Spatial scale	• Impacts affecting <1% of area of any habitat type	• Impacts occurring at local scales	• Impacts occurring at a local to national region scale	• Impacts occurring at a national scale	• Impacts occurring at international region scales
	Temporal reversibility	• Based on expert opinion, if the NIS could be removed, recovery would be expected in days; changes in habitat not measurable against background variability.	• Based on expert opinion, if the NIS could be removed, recovery would be expected in days to a year; no loss of habitat-forming species populations	• Based on expert opinion, if the NIS could be removed, recovery would be expected in less than a decade; no loss of habitat-forming species	• Based on expert opinion, if the NIS could be removed, recovery would be expected in centuries; loss of habitat types and habitat-forming species; local extinction events	• Based on expert opinion, even if the NIS could be removed, recovery would not be expected; loss of multiple habitat types and habitat forming species populations causing significant local extinction; global extinction of at least one species

Value		Negligible to Very Low	Low	Moderate	High	Extreme
Biodiversity	Information Gap				• Limited information is available on the distribution of the biodiversity relative to the NIS distribution; limited information is available on the susceptibility to the NIS or the vulnerability of life history stages of these species	
	Local area of value impacted	• No change in species richness or abundance in presence of NIS detetcted relative to background vairability	• Species richness or abundance is detectably reduced in NIS presence in a small area compared to known areas of distribution (<20%)	• Species richness or abundance is detectably reduced in NIS presence in a moderate area compared to known areas of distribution (<40%)	• Species richness or abundance is detectably reduced in NIS presence in a large area compared to known areas of distribution (<70%);	• Species richness or abundance is detectably reduced in NIS presence in a moderate area compared to known areas of distribution (>70%);
	Alteration of value	• Biodiversity impact by the NIS is not differentiable relative to background variability	• 20% Species richness or abundance is detectably reduced in NIS presence	• 40% Species richness or abundance is detectably reduced in NIS presence	• 70% Species richness or abundance is detectably reduced in NIS presence	• >70% Species richness or abundance is detectably reduced in NIS presence
		• Reductions in species richness and composition are not readily detectable (<10% variation)	• Reductions in species richness and composition are <20%	• Reductions in species richness and composition are <30%	• Reductions in species richness and composition are <70%	• Reductions in species richness and composition are >70%
					• local/ecological extinction of at least one species	• local/ecological extinction of more than one species; global extinction of one species
	Spatial scale	• Impacts occurring at a local scale	• Impacts occurring at a local scale	• Impacts occurring at a national region scale	• Impacts occurring at a national scale	• Impacts occurring at international region scales
	Temporal reversibility	• Based on expert opinion, if the NIS could be removed, recovery would be expected in days; no change in species richness or composition.	• Based on expert opinion, if the NIS could be removed, recovery would be expected in days to months; no loss of species populations; no local extinctions	• Based on expert opinion, if the NIS could be removed, recovery would be expected in years to decades; loss of at least one species or populations; local extinction events.	• Based on expert opinion, if the NIS could be removed, recovery would be expected in centuries; loss several species or populations; multiple local extinction events; one regional extinction	• Based on expert opinion, even if the NIS could be removed, recovery would not be expected; loss of multiple species of populations causing significant local extinctions; global extinction of at least one species

Value		Negligible to Very Low	Low	Moderate	High	Extreme
Trophic interactions (ecosystem)	Information Gap				• Limited information is available on the species composition and abundances of trophic levels and their susceptibility to the NIS; limited information is available on the trophic interactions and fundamental ecosystem processes	
	Local area of value impacted	NA	NA	NA	NA	NA
	Alteration of value	• No significant changes trophic level species composition observed; no change in relative abundance of trophic levels (based on biomass)	• Minor changes (<10%) in relative abundance of trophic levels (based on biomass); • <10% reduction of population abundances for top predator species	• Measurable changes (<30%) in relative abundance of trophic levels (based on biomass); • <30% reduction of population abundances for top predator species	• Major changes (<70%) in relative abundance of trophic levels (based on biomass); • <70% reduction of population abundances for top predator species; • <30% reduction of population abundances for primary producer species	• >70% change in relative abundance of trophic levels (based on biomass); • >70% reduction of population abundances for top predator species; • >30% reduction of population abundances for primary producer species
	Spatial scale		• Impacts occurring at local scales	• Impacts occurring at national region scales	• Impacts occurring at national scales	• Impacts occurring at international region scales
	Temporal reversibility	• Based on expert opinion, if the NIS could be removed, recovery would be expected in days to weeks; changes in trophic interactions not measurable against background variability.	• Based on expert opinion, if the NIS could be removed, recovery would be expected in weeks to months; no loss of keystone species populations	• Based on expert opinion, if the NIS could be removed, recovery would be expected in years to decades; loss of keystone species populations; no loss of primary producer populations	• Based on expert opinion, if the NIS could be removed, recovery would be expected in centuries; loss of keystone species populations; changes in trophic levels; loss of primary producer populations; local extinction events.	• Based on expert opinion, even if the NIS could be removed, recovery would not be expected; loss of trophic levels; potential trophic cascades resulting in significant changes to ecosystem structure, alteration of biodiversity patterns and changes to ecosystem function; significant local extinctions

Value		Negligible to Very Low	Low	Moderate	High	Extreme
Nationally important and ecologically valuable species	Information Gap				• Limited information is available on the susceptibility to impact or the behavioural vulnerability of the nationally important and/or ecologically valuable species to the NIS	
	Local area of value impacted	• No nationally important and/or ecologically valuable species impacted by NIS; impacts on behaviour not detectable	• NIS impact to Nationally important and/or ecologically valuable species is restricted to <1% of compared to Nationally important and/or ecologically valuable species' ranges	• NIS impact to Nationally important and/or ecologically valuable species is restricted to <10% of compared to Nationally important and/or ecologically valuable species' ranges	• NIS impact to Nationally important and/or ecologically valuable species is restricted to <20% of compared to Nationally important and/or ecologically valuable species' ranges	• NIS impact to Nationally important and/or ecologically valuable species is deetcted in >20% of compared to Nationally important and/or ecologically valuable species' ranges
	Alteration of value	• No nationally important and/or ecologically valuable species impacted by NIS; impacts on behaviour not detectable	• The number of Nationally important and/or ecologically valuable species impacted by NIS is <1% compared to impact from other hazards • Reductions in nationally important and/or ecologically valuable species population abundances are <1%	• The number of Nationally important and/or ecologically valuable species impacted by NIS is <10% compared to impact from other hazards • Reductions in nationally important and/or ecologically valuable species population abundances are <10%	• The number of Nationally important and/or ecologically valuable species impacted by NIS is <20% compared to impact from other hazards • Reductions in nationally important and/or ecologically valuable species population abundances are <20%	• The number of Nationally important and/or ecologically valuable species impacted by NIS is >20% compared to impact from other hazards • Reductions in nationally important and/or ecologically valuable species population abundances are >20%
	Spatial scale	NA	NA	NA	NA	NA
	Temporal reversibility	• Based on expert opinion, if the NIS could be removed, recovery would be expected; no loss of nationally important and/or ecologically valuable individuals.	• Based on expert opinion, if the NIS could be removed, recovery would be expected in months to years; no loss of nationally important and/or ecologically valuable species populations	• Based on expert opinion, if the NIS could be removed, recovery would be expected in years to decades; no loss of nationally important and/or ecologically valuable species populations; potential loss of genetic diversity.	• Based on expert opinion, if the NIS could be removed, recovery would be expected in centuries; loss of nationally important and/or ecologically valuable species populations causing local extinction; measurable loss of genetic diversity	• Based on expert opinion, even if the NIS could be removed, recovery would not be expected; loss of nationally important and/or ecologically valuable species populations causing global extinction; local extinction of multiple nationally important and/or ecologically valuable species; significant loss of genetic diversity of multiple nationally important and/or ecologically

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Value		Negligible to Very Low	Low	Moderate	High	Extreme
Assets (places) of environmental significance	Information Gap				• Limited information is available on the assets of environmental significance and their susceptibility to the NIS	
	Local area of value impacted	• No significant changes to assets of environmental significance	• Localised (<10% of total asset area) effects on assets of environmental significance	• Regional (<30% of total asset area) effects on assets of environmental significance	• Regional (<70% of total asset area) effects on assetss of environmental significance;	• National (>70% of total asset area) effects on assets of environmental significance affected/removed; significant changes to assets of environmental significance
	Alteration of value	• No significant changes to assets of environmental significance	• <10% reduction in intrinsic value of at least one environmental significance	• <30% reduction in intrinsic value ofat least one asset of environmental significance • More than one asset of environmental significance affected/removed • localised loss of at least one asset of environmental significance	• <70% reduction in intrinsic value ofat least one asset of environmental significance • More than 30% of assets of environmental significance affected/removed • Regional loss of at least one asset of environmental significance	• >70% reduction in intrinsic value of at least one asset of environmental significance • More than 50% of assets of environmental significance affected/removed • National/Global loss of more than one asset of environmental significance
	Spatial scale	NA	NA	NA	NA	NA
	Temporal reversibility	• Based on expert opinion, if the NIS could be removed, recovery would be expected in days; changes in assets of environmental significance not measurable against background variability.	• Based on expert opinion, if the NIS could be removed, recovery would be expected in weeks to months; no complete loss of assets of environmental significance	• Based on expert opinion, if the NIS could be removed, recovery would be expected in years to decades; no complete loss of assets of environmental significance	• Based on expert opinion, if the NIS could be removed, recovery would be expected in centuries; minimal loss of assets of environmental significance	• Based on expert opinion, even if the NIS could be removed, recovery would not be expected; national/global loss of multiple assets of environmental significance

Value		Negligible to Very Low	Low	Moderate	High	Extreme
Social values	Information Gap				• Limited information is available on social impacts of the NIS	
	Local area of value impacted		• Social activity is reduced to less than 90% of its original area (spatial context) within the region	• Social activity is reduced to less than 80% of its original area (spatial context) within the region	• Social activity is reduced to less than 70% of its original area (spatial context) within the region	• Social activity is reduced to less than 60% of its original area (spatial context) within the region
	Alteration of value	• Social activity reduction is minimal (<1%) • Degradation of amenity used by 80% of people over an local scale is minimal (<1%) • No significant changes to nationally important places • No discernable change in strength of social activities	• Social activity reduction is <10% • <10% degradation of amenity used by 80% of people across a local scale • Localised affects on nationally important places in <10% of nationally important places; measurable changes to nationally important places; <10% reduction in intrinsic value of nationally important places • Reduction of strength in separate social activities is <10%	• Social activity reduction is <20% • <30% degradation of amenity used by 80% of people across a regional scale • <30% of nationally important places affected; moderate changes to nationally important places; <30% reduction in intrinsic value of nationally important places • Reduction of strength in separate social activities is <20%	• Social activity reduction is <40% • <70% degradation of amenity used by 80% of people across a nation • <70% of nationally important places affected; major changes to nationally important places; <70% reduction in intrinsic value of the nationally important places; loss of at least one nationally important place • Reduction of strength in separate social activities is <40%	• Social activity reduction is >40% • >70% degradation of amenity used by 80% of people across a nation, or across international borders • >70% of nationally important places affected; significant changes to nationally important places; loss of more than one nationally important place • Reduction of strength in separate social activities is >40%
	Spatial scale		• Social activity reduction is restricted to the locality of incursion/impact	• Social activity reduction is restricted to the country region of incursion/impact	• Social activity is reduced at national scales	• Social activity is reduced in international regions
	Temporal reversibility	• Based on expert opinion, if the NIS could be removed, recovery would be expected in days.	• Based on expert opinion, if the NIS could be removed, recovery would be expected in weeks to months, no loss of any social activities.	• Based on expert opinion, if the NIS could be removed, recovery would be expected in less than a year and loss of at least one tourism activities.	• Based on expert opinion, if the NIS could be removed, recovery would be expected in less than a decade and loss of at least one tourism activities.	• Based on expert opinion, if the NIS could be removed, recovery would not be expected and loss of multiple tourism activities.

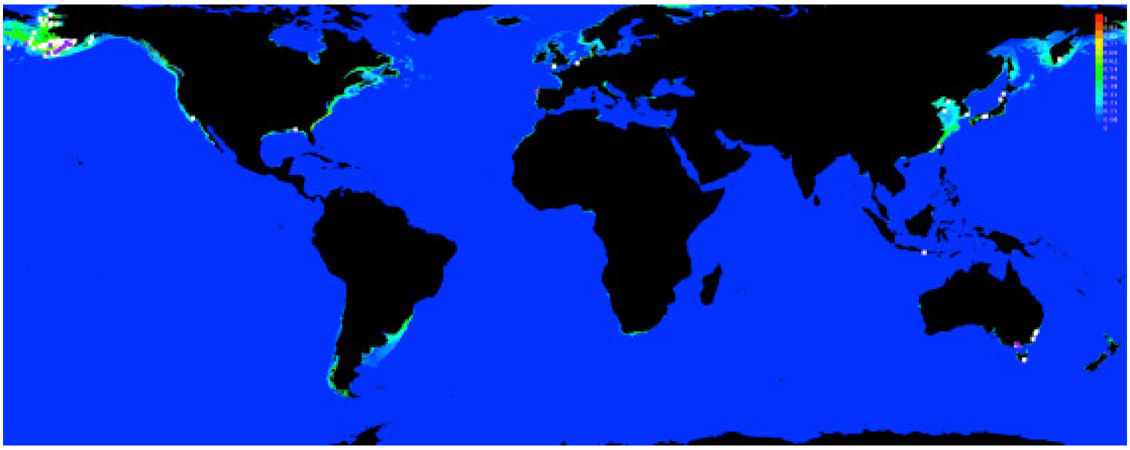
Value		Negligible to Very Low	Low	Moderate	High	Extreme
Cultural values	Information Gap				• Limited information is available on cultural impacts of the NIS	
	Local area of value impacted	• No significant changes to culturally important places	• Localised affects on culturally important places in <10% of culturally important places; measurable changes to culturally important places; <10% reduction in intrinsic value of culturally important places	• <30% of culturally important places affected; moderate changes to nationally important places; <30% reduction in intrinsic value of culturally important places	• <70% of culturally important places affected; major changes to culturally important places; <70% reduction in intrinsic value of the culturally important places; loss of at least one culturally important place	• >70% of culturally important places affected; significant changes to culturally important places; loss of more than one culturally important place
	Alteration of value	• Cultural activity reduction is minimal (<1%) • Degradation of cultural amenities used by 80% of people over an local scale is minimal (<1%) • No discernable change in strength of cultural activities	• Cultural activity reduction is <10% • <10% degradation of cultural amenities used by 80% of people across a local scale • Reduction of strength in separate cultural activities is <10% • Cultural activity is reduced to less than 90% of its original area (spatial context) within the region	• Cultural activity reduction is <20% • <30% degradation of cultural amenities used by 80% of people across a regional scale • Reduction of strength in separate cultural activities is <20% • Cultural activity is reduced to less than 80% of its original area (spatial context) within the region	• Cultural activity reduction is <40% • <70% degradation of cultural amenities used by 80% of people across a nation • Reduction of strength in separate cultural activities is <40% • Cultural activity is reduced to less than 70% of its original area (spatial context) within the region	• Cultural activity reduction is >40% • >70% degradation of cultural amenities used by 80% of people across a nation, or across international borders • Reduction of strength in separate cultural activities is >40% • Cultural activity is reduced to less than 60% of its original area (spatial context) within the region
	Spatial scale		• Cultural activity reduction is restricted to the locality of incursion/impact	• Cultural activity reduction is restricted to the country region of incursion/impact	• Cultural activity is reduced at national scales	• Cultural activity is reduced in international regions
	Temporal reversibility	• Based on expert opinion, if the NIS could be removed, recovery would be expected in days.	• Based on expert opinion, if the NIS could be removed, recovery would be expected in weeks to months, no loss of any social activities.	• Based on expert opinion, if the NIS could be removed, recovery would be expected in less than a year and loss of at least one social activities.	• Based on expert opinion, if the NIS could be removed, recovery would be expected in less than a decade and loss of at least one social activity.	• Based on expert opinion, even if the NIS could be removed, recovery would not be expected and loss of multiple social activities.

Value		Negligible to Very Low	Low	Moderate	High	Extreme
National image (iconic places or species)	Information Gap				• Limited information is available on the NIS impacts	
	Local area of value impacted	nationally important places or iconic species	nationally important places; iconic species ... <10% of range	important places affected; iconic species affected in <30% of range	important places affected; iconic species affected in <50% of range	important places affected; iconic species ... national scales
	Alteration of value	• National image reduction is	• National image intrinsic	• National image intrinsic	• National image intrinsic	• National image intrinsic
	Spatial scale		restricted to the locality of incursion/impact	restricted to the country region of incursion/impact	national scales	neighbouring countries
	Temporal reversibility	• Based on expert opinion, if the NIS could be removed,	• Based on expert opinion, if the NIS could be removed,	• Based on expert opinion, if the NIS could be removed,	• Based on expert opinion, if the NIS could be removed,	• Based on expert opinion, if the NIS could be removed,

Value		Negligible to Very Low	Low	Moderate	High	Extreme
Aesthetic values	Information Gap				• Limited information is available on aesthetic impacts of the NIS	
	Local area of value impacted		• Aesthetic appeal is reduced to <90% of its original area (spatial context) within the region of incursion/impact	• Aesthetic appeal is reduced to <60% of its original area (spatial context) within the region of incursion/impact	• Aesthetic appeal is reduced to <30% of its original area (spatial context) within the region of incursion/impact	• Aesthetic appeal is reduced to <10% of its original area (spatial context) within the region of incursion/impact
	Alteration of value	• Aesthetic appeal reduction is minimal (<1%)	• Aesthetic appeal of locations is <10% reduced	• Aesthetic appeal of locations is <20% reduced • Reduction of strength in separate aesthetic appeal is <20%	• Aesthetic appeal of locations is <40% reduced • Reduction of strength in separate aesthetic appeal is <40%	• Aesthetic appeal of locations is >40% reduced • Reduction of strength in separate aesthetic appeal is >40%
	Spatial scale	• No discernable change in original area of aesthetic appeal (spatial context) within the region	• Aesthetic appeal is reduced in the locality of incursion/impact	• Aesthetic appeal is reduced in country region scales	• Aesthetic appeal is reduced at national scale	• Aesthetic appeal is reduced in international regions
	Temporal reversibility	• Based on expert opinion, if the NIS could be removed, recovery would be expected in days.	• Based on expert opinion, if the NIS could be removed, recovery would be expected in weeks to months	• Based on expert opinion, if the NIS could be removed, recovery would be expected in less than a year	• Based on expert opinion, if the NIS could be removed, recovery would be expected in less than a decade	• Based on expert opinion, even if the NIS could be removed, recovery would not be expected

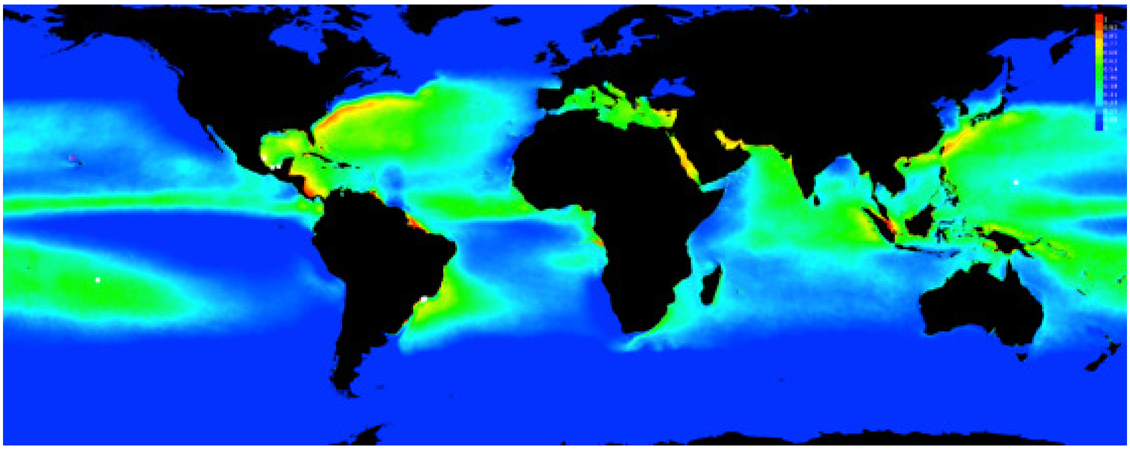
Appendix VI

1. Habitat suitability map for *Asteria amurensis*

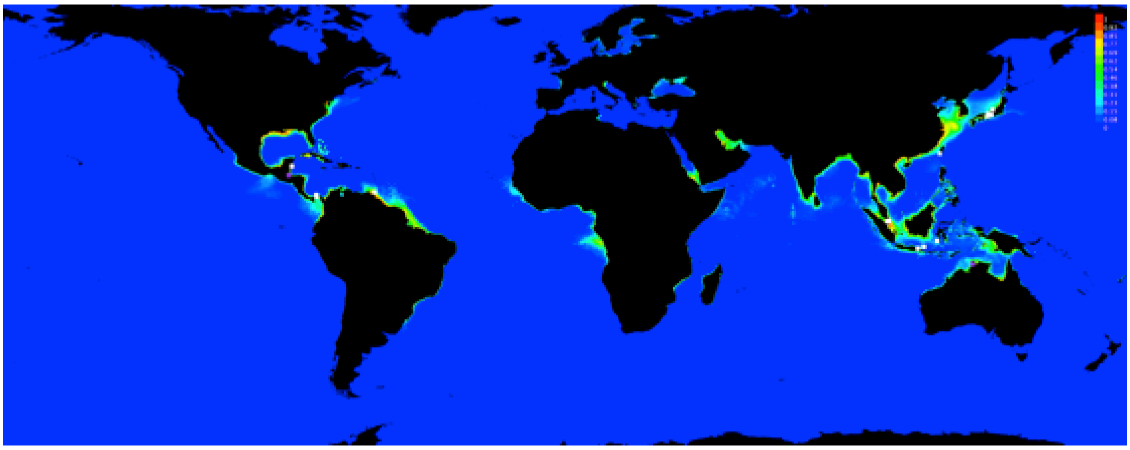


Variable	Percent contribution	Variable	Percent contribution
chlomean	44.8	ph	2.2
chlomax	18.9	dissox	1.9
salinity	16.8	phos	1.3
nitrate	4.1	sstmean	1.2
sstmax	3.9	parmean	1.2
sstmin	3.8		

2. Habitat suitability map for *Chthamalus proteus*

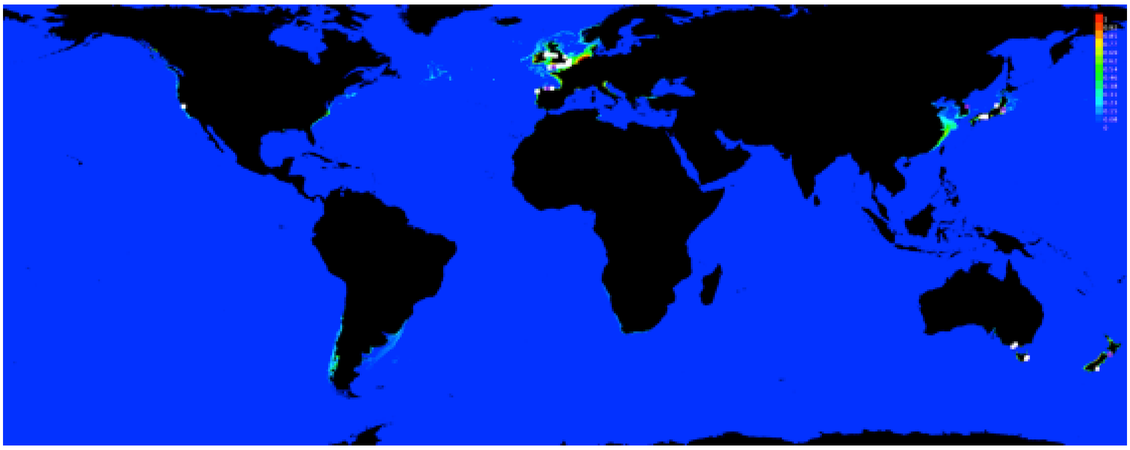


3. Habitat suitability map for Mytilopsis sallei



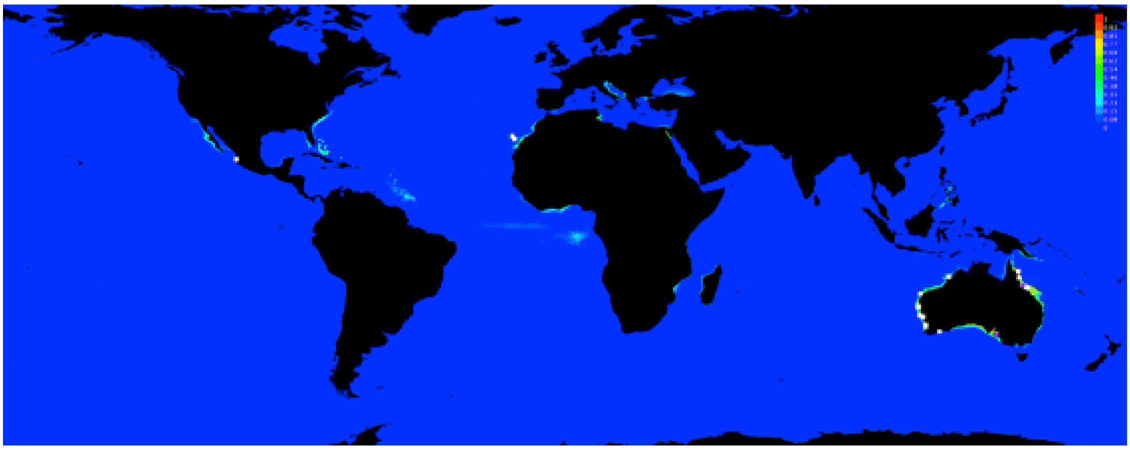
Variable	Percent contribution	Variable	Percent contribution
chlomean	41.3	salinity	1.8
sstmax	29.6	sstmin	1.2
chlomax	14.6	nitrate	0.6
phos	4.4	parmean	0.3
ph	3.1	sstmean	0.3
dissox	2.9		

4. Habitat suitability map for *Undaria pinnatifida*



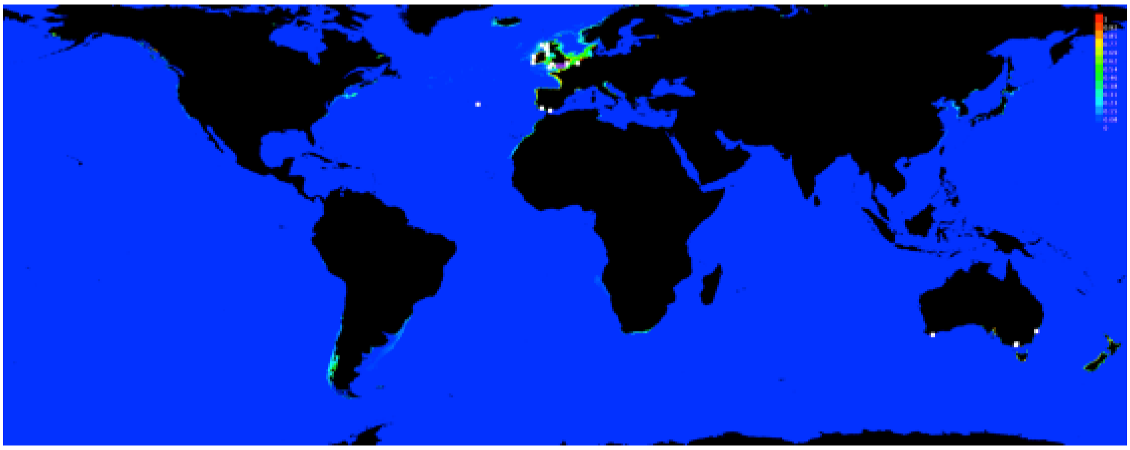
Variable	Percent contribution	Variable	Percent contribution
chlomean	55.2	sstmax	0.9
sstmin	23.4	salinity	0.8
chlomax	11.2	nitrate	0.3
parmean	3.1	ph	0.1
sstmena	2.7	dissox	0
phos	2.2		

5. Habitat suitability map for *Caulerpa cylindracea*



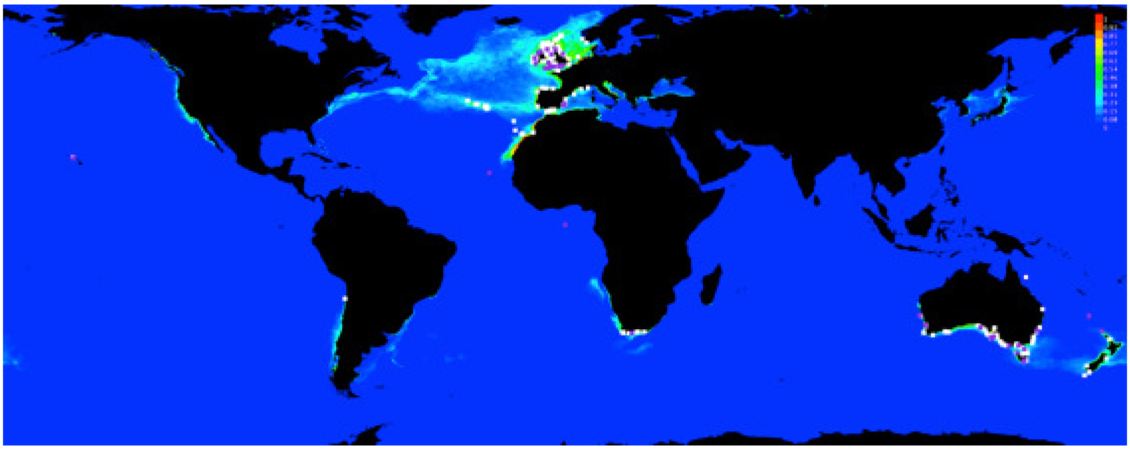
Variable	Percent contribution	Variable	Percent contribution
ph	27	parmean	2.7
chlomean	25	dissox	0.8
nitrate	17.4	chlomax	0.5
phos	13.1	salinity	0.3
sstmin	8	sstmean	0
sstmax	5.2		

6. Habitat suitability map for *Codium fragile*



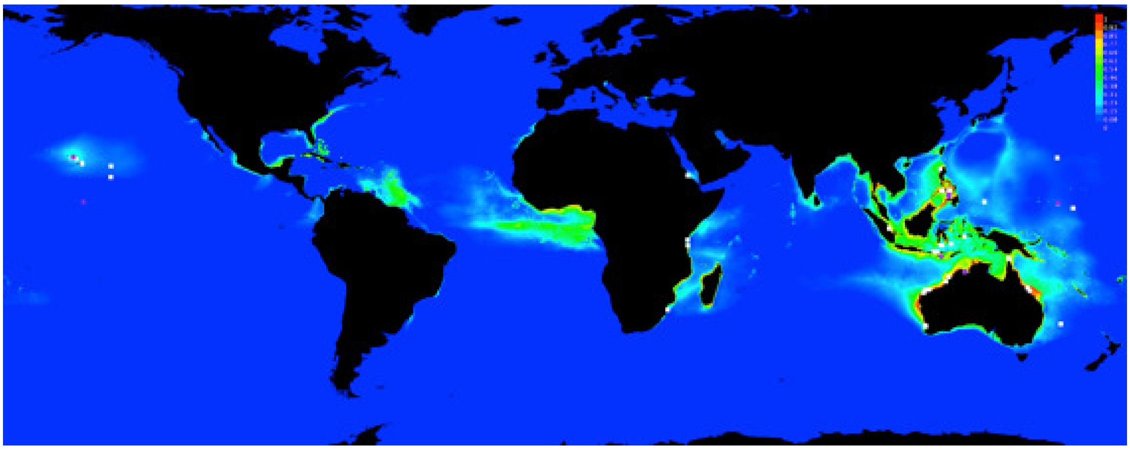
Variable	Percent contribution	Variable	Percent contribution
chlomean	62.5	salinity	1.6
sstmax	11.3	nitrate	1.2
sstmin	10.7	sstmean	0.1
phos	9	chlomax	0
parmean	2.1	ph	0
dissox	1.6		

7. Habitat suitability map for *Aspargopsis armata*



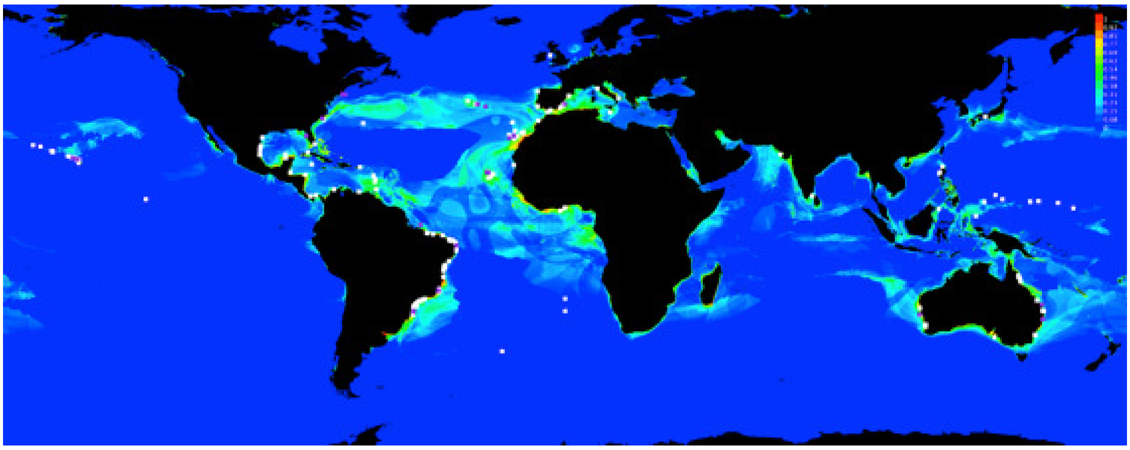
Variable	Percent contribution	Variable	Percent contribution
chlomean	42.7	salinity	4.8
sstmax	21.4	sstmin	1.3
chlomax	9.8	ph	0.9
phos	7	nitrtate	0.6
dissox	6.6	parmean	0
sstmax	4.9		

8. Habitat suitability map for *Gracilaria salicornia*



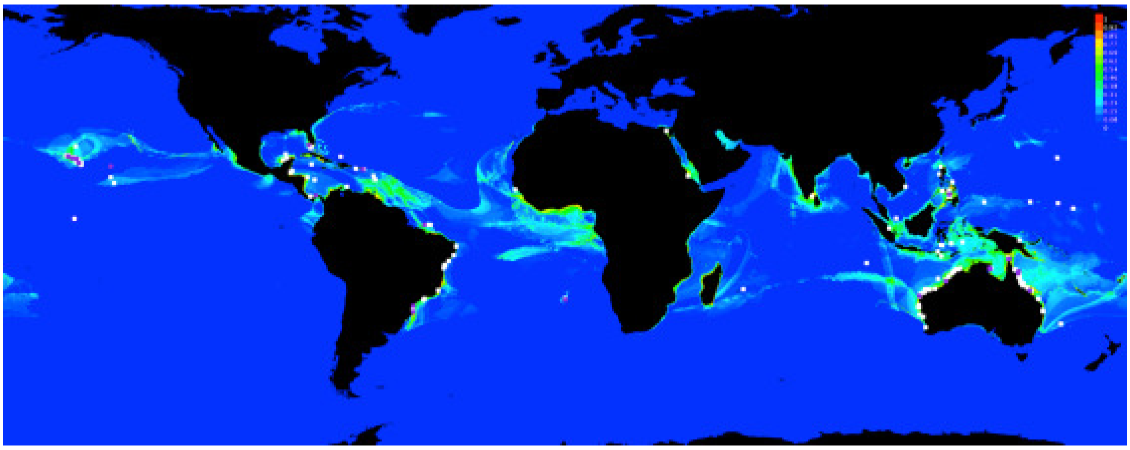
Variable	Percent contribution	Variable	Percent contribution
nitrate	40.5	ph	2.4
sstmin	17.2	salinity	2.2
chlomean	16.8	dissox	1.9
chlomax	10.7	parmean	0.7
phos	3.9	sstmean	0.1
sstmax	3.7		

9. Habitat suitability map for *Hypnea musciformis*



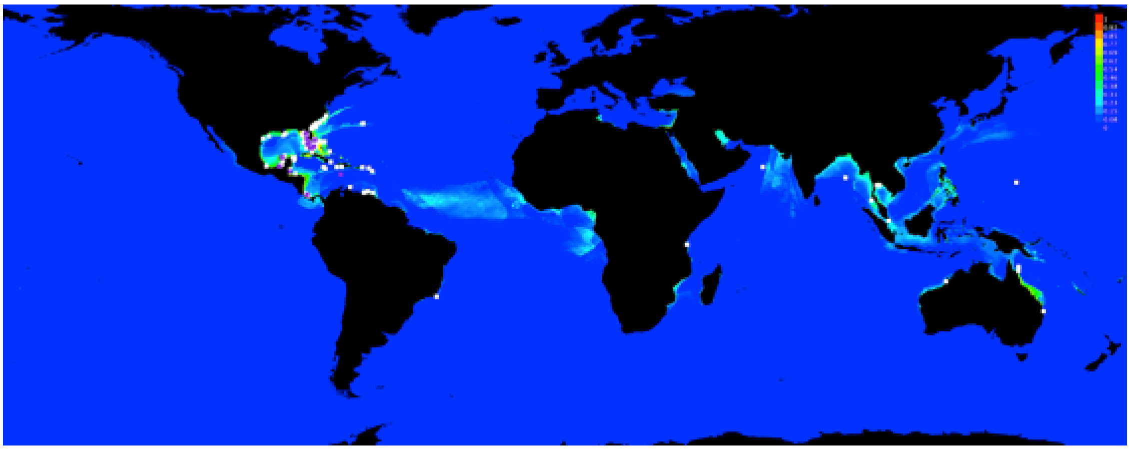
Variable	Percent contribution	Variable	Percent contribution
chlomean	37	sstmean	1.7
nitrate	29.4	parmean	1.2
salinity	11.8	sstmin	0.6
sstmax	8.2	chlomax	0.5
phos	5.6	dissox	0.4
ph	3.6		

10. Habitat suitability map for *Acanthophora spicifera*



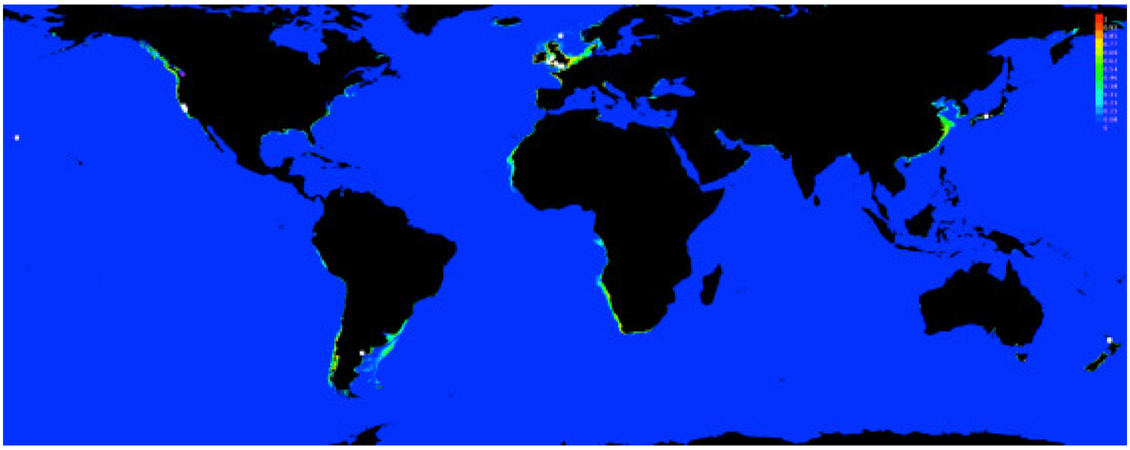
Variable	Percent contribution	Variable	Percent contribution
nitrate	24.1	phos	3.6
sstmean	21.1	sstmax	3.4
chlomean	17.9	sstmin	1.3
chlomax	14.1	parmean	1.1
ph	9.3	dissox	0.1
salinity	3.9		

11. Habitat suitability map for *Chama macerophylla*



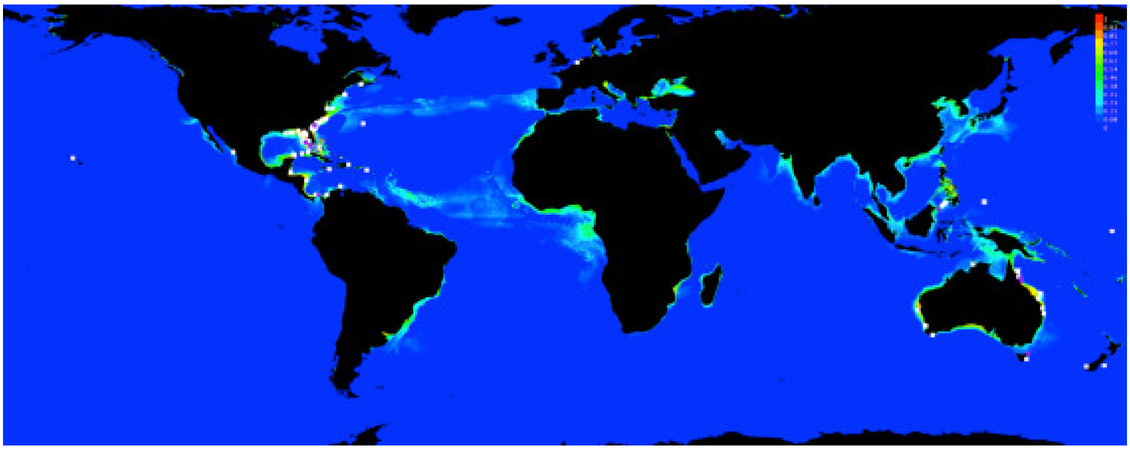
Variable	Percent contribution	Variable	Percent contribution
sstmax	31.2	ph	1.3
chlomean	28.4	sstmean	0.5
phos	19.1	sstmin	0.3
nitrate	8.5	dissox	0.2
salinity	6.9	chlomax	0
parmean	3.6		

12. Habitat suitability map for *Diadumene lineata*



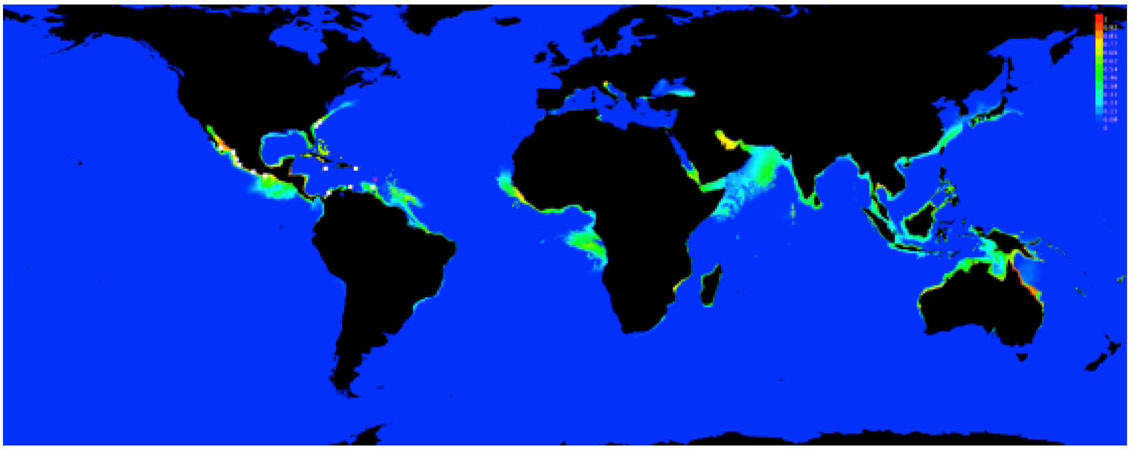
Variable	Percent contribution	Variable	Percent contribution
chlomean	74.9	parmean	0.8
sstmin	17.3	chlomax	0.1
nitrate	3	ph	0.1
sstmax	1.7	dissox	0
salinity	1.1	sstmean	0
phos	1		

13. Habitat suitability map for *Didemnum candidum*



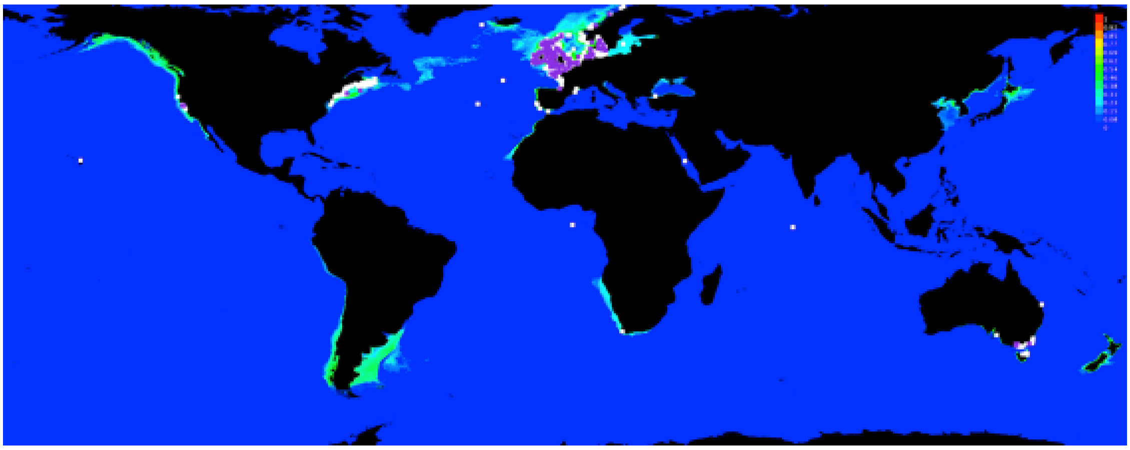
Variable	Percent contribution	Variable	Percent contribution
chlomean	33.8	ph	2.7
nitrate	33.2	dissox	1.4
phos	11.2	sstmin	0.6
parmean	10.5	chlomax	0.2
salinity	3.5	sstmean	0.1
sstmax	2.8		

14. Habitat suitability map for *Haliclona caerulea*



Variable	Percent contribution	Variable	Percent contribution
chlomean	45.3	dissox	1.4
sstmax	27.6	phos	0.9
sstmin	14.8	salinity	0.6
mitrate	4.6	parmean	0.4
ph	2.8	sstmean	0
chlomax	1.6		

15. Habitat suitability map for *Carcinus maenas*



Variable	Percent contribution	Variable	Percent contribution
chlomean	55.2	chlomax	0.9
sstmean	23.4	parmean	0.8
sstmax	11.2	dissox	0.3
sstmin	3.1	nitrate	0.1
salinity	2.7	ph	0
phos	2.2		

Appendix VII

Action plan to minimize risks of marine invasive species introduction into the Galapagos Marine Reserve

Final report from the international workshop on marine bio-invasions into tropical island ecosystems
CDRS - 24-27 February 2015

Edited by:
Inti Keith – Charles Darwin Foundation
Verónica Toral-Granda – Charles Darwin University
Puerto Ayora, April 2015

To cite from this document:

Keith, I & Toral, V, 2015. Action plan to minimize risks of marine invasive species introduction into the Galapagos Marine Reserve. Charles Darwin Foundation, Santa Cruz, Galapagos, Ecuador.

The international workshop on marine bio-invasions into tropical island ecosystems was held thanks to the support of the Darwin Initiative and Galapagos Conservancy. The CDF wishes to highlight the fundamental role played by the other institutions promoting this project: the Ministry of Environment (MAE) through the Directorate of the Galapagos National Park (DPNG) and the Bio-security and Quarantine Regulation and Control Agency for Galapagos (ABG), the National Directorate of Aquatic Spaces (DIRNEA) and the Naval Oceanographic Institute (INOCAR).

Acknowledgments:

In addition to the institutions promoting the project, we would like to thank all the institutions attending the workshop for the support they provided, and we look forward to continuing to work together:Under-Secretariat of Marine and Coastal Management, Technical Secretariat of the Sea, Under-Secretariat of Ports and Maritime and Riverway Transport, Smithsonian Environmental Research Center, University of the Azores, University of Waikato, University of Southampton, University of Dundee, Williams College, Smithsonian Tropical Research Institute, Island Conservation, World Wildlife Fund, Conservation International, Nazca Institute, WILDAID, and San Francisco de Quito University. Our special thanks to everyone who attended the workshop, adding that this output has been achieved thanks to the inputs and contributions made by all these participants.

Mission of the CDF:

"Provide knowledge and support through scientific research and complementary actions to ensure conservation of the environment and biodiversity in the Archipelago of Galapagos".

List of Participants

The international workshop on marine bio-invasions in tropical island ecosystems was organized by Inti Keith of the Charles Darwin Foundation (CDF) and James Carlton of Williams College with collaboration by the universities of Southampton and Dundee and support from local institutions: the Directorate of the Galapagos National Park (DPNG), the Bio-security and Quarantine Regulation and Control Agency for Galapagos (ABG), National Directorate of Aquatic Spaces (DIRNEA) and the Naval Oceanographic Institute (INOCAR). It was facilitated by Verónica Toral-Granda.

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Acronyms

ABG	Bio-security and Quarantine Regulation and Control Agency for Galapagos
CGREG	Galapagos Special Regime Government Council
CI	Conservation International
DGNP	Directorate of the Galapagos National Park
DI	Darwin Initiative
DIGMER	National Directorate of Aquatic Spaces
CDRS	Charles Darwin Research Station
CDF	Charles Darwin Foundation
GC	Galapagos Conservancy
IC	Island Conservation
INOCAR	Naval Oceanographic Institute
LOREG	General Law on the Galapagos Special Regime
MAE	Ministry of Environment of Ecuador
MTOP	Ministry of Transport and Public Works
PNG	Galapagos National Park
RMG	Galapagos Marine Reserve
SERC	Smithsonian Environmental Research Center
SPTMF	Under-Secretariat of Maritime and Riverway Ports and Transport
STRI	Smithsonian Tropical Research Institute
USFQ	San Francisco de Quito University

Executive Summary

The introduction of non-native species has been identified as the second-greatest reason for the loss of biodiversity worldwide, following only the destruction of their habitat (IUCN 2011). The number of biological invasions has increased in recent decades, above all due to species spread by growing trade, transport, tourism and the breakdown of natural barriers such as currents, landmasses and temperature ranges that once limited the movement of species (Carlton, 1996; Seebens, 2013). Although less visible than organisms on land, marine invasive species pose a threat to the ecosystem that must be clarified urgently. The marine ecosystem of Galapagos features a number of different biological communities, due to the confluence of currents and their connectivity with the Eastern Tropical Pacific (ETP). The Galapagos Marine Reserve (RMG) is also home to several endemic species that are regularly subjected to climate variability by El Niño phenomenon events. Possible invasion by marine species into the RMG due to climate change, connectivity and increasing maritime traffic currently poses a risk for local biodiversity and a management challenge for Ecuadorian authorities. Marine invasive species are largely introduced by the different types of vessels arriving from various parts of the world and from mainland Ecuador. Some non-native species already present are considered cryptogenic because when they arrived and how they entered the RMG is unknown. There are also species with high potential to be introduced into the Islands, such as snowflake coral (*Carijoa riisei),* already reported in mainland Ecuador and on Malpelo Island, Colombia.

The purpose of this document is to covey the risk posed by non-native marine species already established in the RMG and those that are potentially invasive. It would be necessary to assess knowledge about non-native species and discuss, with all participating institutions, what prevention, monitoring and – if required – remediation measures would be called for to minimize any negative impact they might cause on the marine biodiversity, ecosystem services and the RMG's resilience, and to produce an action plan.

The Project on Marine Invasive Species, for prevention, detection and management, has been led by the Charles Darwin Foundation (CDF) since 2012, jointly with the Directorate of the Galapagos National Park (DPNG), the Naval Oceanographic Institute (INOCAR), the National Directorate of Aquatic Spaces (DIRNEA), the Bio-security and Quarantine Regulation and Control Agency for Galapagos (ABG) and Southampton and Dundee Universities in the United Kingdom, with funding by the UK Darwin Initiative and the Galapagos Conservancy. To continue expanding the project and efforts to minimize the negative impacts that could be caused by non-native species to the RMG, it is critical to analyze the cost required to achieve the envisioned aims. A cost has been calculated of \$507,000, which must be divided into different research and management issues, classified by the priority of the question. This is outlined in Attachment III.

The Action Plan to minimize risks of introducing marine invasive species into the Galapagos Marine Reserve requires the commitment of all participating institutions and multi-institutional work to achieve the goals set forth in this plan, and thereby conserve the RMG's biodiversity.

1. Background

In recent years, interest in the presence of, and research about, non-native species in tropical marine ecosystems, has increased, including rocky coastlines, coral reefs and mangroves, due to the environmental and economic impacts they have generated worldwide. However, for many tropical regions, the scale of the diversity of invasions is little-known, with a gap in knowledge about marine bio-invasions on tropical islands. In 2009, a study was completed on marine bio-invasions in the Hawaiian Islands (updated in 2014), and research is now underway in the Galapagos Islands, Macaronesia, the Caribbean, the Bermudas and in other places.

The goal of the project on marine invasive species for their prevention, detection and management in the Galapagos Marine Reserve is to minimize the negative impacts of invasive species on marine biodiversity, ecosystem services and the health of the RMG. As part of the project, an international workshop was organized, with experts on marine bio-invasions from different parts of the world, and authorities from a number of Ecuadorian Government institutions. This workshop provided the opportunity to share data, points of view and approaches to the scale, current and future status of marine biological invasions of tropical islands in general and the Galapagos Marine Reserve (RMG) in particular, and to identify top-priority actions to protect the Galapagos Islands from marine invasions.

2. International workshop on marine bio-invasions into tropical island ecosystems

The Charles Darwin Research Station (CDRS) – as the operational branch of the Charles Darwin Foundation – hosted the first international workshop on marine bio-invasions in tropical island ecosystems. The workshop was held from February 24 to 27, 2015 in Puerto Ayora, Santa Cruz Island. This event, organized by the Charles Darwin Foundation (CDF), Williams College (United States) and the University of Southampton (England) and the University of Dundee (Scotland), was one of the activities planned under the Research Project on Marine Invasive Species for Prevention, Detection and Management in the Galapagos Marine Reserve (RMG). The workshop included two days of scientific lectures by local institutions from Ecuador's mainland and international experts, one day of group work to generate inputs for the Action **Plan for Marine Invasive Species in the RMG**, and finally a field trip to Tortuga Bay in Santa Cruz to analyze the particular features of marine ecosystems and assess the presence of invasive marine species. For the details on the agenda and working groups, please see Attachment I. Additionally, all workshop presentations are available on-line at the following link:
https://app.box.com/s/6lmu90rqt55ehesemb30rnlmydeecbqh

3. Goals of the international workshop on marine bio-invasions

This workshop gathered researchers specializing in marine bio-invasions to share data, viewpoints and approaches to the current and future status of marine bio-invasions on tropical islands, with special emphasis on the Galapagos Islands. The workshop focused on two goals, to attempt to cover various aspects of marine bio-invasions in tropical island ecosystems:

First objective: To assess our knowledge about marine invasive species in tropical archipelagos in general and discuss what is being done and what remains to be done.

- Biodiversity in marine invasions on tropical islands: a) the scale and constraints on understanding invasions that occurred in the past; (b) the contribution of modern biogeography and new genetic techniques to help refine knowledge about these invasions; and (c) patterns of invasive biodiversity among tropical islands around the world.

- The science of invasions in 2015: The current status of the science of marine bio-invasions on tropical islands, including (a) the current knowledge about vectors (such as: ballast water, fouling on ships' hulls, movement of diving gear, marine garbage, etc.) and (b) current experimental and quantitative work to determine patterns and processes of invasions in tropical ecosystems.

- Future invasions: (a) future scenarios for invasions regarding climate change models, changes in the intensity of vectors, routes, or pressure of propagules with increasing commercial / recreational traffic and other phenomena influencing the potential success of new invaders; (b) vector management strategies (current and future) and legal / regulatory frameworks; and, (c) foreseeable changes in vectors, vectors' routes and propagule pressure.

Second objective: Produce a strategic research plan for Galapagos, informed by all participating institutions.

4. Expected workshop outputs and outcomes[1]

- **Overview with literature backing:** An article in a peer-reviewed journal on the status of our knowledge on marine bio-invasions in tropical islands.

- **Threats from invasive species:** Identification of the potential threats from marine bio-invasions for economic sustainability, ecosystem and endangered and threatened marine species on tropical islands.

- **Research opportunities:** Research priorities, including possible funding sources.

[1]The first three outputs are separate documents, not included herein.

- **Action plan to minimize risks of marine invasive species introduction into the Galapagos Marine Reserve:** A road map with recommendations for the Ecuadorian Government in its proactive efforts to control marine invasive species in the RMG.

5. Action plan to minimize risks of marine invasive species introduction into the Galapagos Marine Reserve (RMG)

Considering the incalculable risk posed by marine invasive species for conservation of ecosystems and species in the RMG, negative impacts must be minimized that could result from the arrival, establishment and proliferation of marine invasive species in the RMG, through research and strategic management actions. For this purpose, this action plan will outline the research questions that must be answered in order to assemble an archipelago-wide strategy to prevent and manage marine invasive species. Each section has a research question, followed by the activities required to answer it. Each activity gives its priority, where it will be carried out, the resources required, its duration, the institutions involved and the funds required to successfully conduct the activity.

1. How many non-native marine species are established in the RMG?

Since 2012, when the marine invasive species project began, six non-native marine species have been identified that are established in the RMG: *Caulerpa racemosa, Aspargopsis taxiformis, Bugula neritina, Pennaria disticha, Cardisoma crassum*and *Acanthaster planci*. Nevertheless, thanks to the expertise present at the workshop, a seventh species was identified, spaghetti briozoo *(Zoobotryon verticillatum)* (Attachment II). The discovery of this last non-native marine species shows the need for constant monitoring and search for non-native marine species in the RMG and the main harbors. The species *Caulerpa racemosa, Aspargopsis taxiformis, Bugula neritina, Pennaria disticha* and *Acanthaster planci* are also considered cryptogenic species because we have no information on how or when they reached the islands. These species are currently competing with native species.

1.1 Targeted search for marine invasive species around the RMG

Marine ecosystems in Galapagos feature unique biological communities, with a high incidence of endemic species. They have no defense mechanisms against non-native species, with which they did not evolve. Additionally, the lack of physical barriers (such as mountain ranges and rivers) in the marine environment facilitates the spread of these species within the RMG. It is important to continue targeted searches for invasive species in key sites around the RMG to prevent possible serious invasions that could affect marine ecosystems, and identify the deterioration or damage that the invasive species is causing for marine biodiversity.

- **Priority:** High
- **Research location:** Galapagos Islands
- **Resources required:** Research divers, marine transport, diving gear and field materials, laboratories and materials
- **Duration of the research:** 1-3 years
- **Institutional collaboration:** CDF, DGNP, ABG

- **Funding:** Funds are required for the salary of a researcher at the CDF, to rent a boat, for diving equipment and field materials, approximately $100,000.

1.2 Monitoring the main harbors in the RMG

Galapagos, because of its geographic isolation, depends on cargo ships from mainland Ecuador to supply the resident and tourist populations' basic social needs. These harbors are the port of entry for possible invasive marine species and receive a high percentage of local, national and international marine traffic annually. Continual checking of bays and especially the structures in the Archipelago's main ports is considered a high priority because numerous organisms can adhere to these structures that may be considered invasive.

- **Priority:** High

- **Research location:** Galapagos Islands (Santa Cruz, San Cristóbal, Isabela, Floreana, and Baltra)

- **Resources required:** Research divers, marine transport, diving gear and field materials, inter-island transport and daily subsistence allowances (per diems).

- **Duration of the research:** Indefinite

- **Institutional collaboration:** CDF, ABG

- **Funding:** Approximately $20,000 will be required to pay marine transport between islands and per diems for two researchers.

1.3 Monitoring abundance and distribution of non-native species present in the RMG

During the marine invasive species project, key sites were selected around the Archipelago to monitor any possible invasion that might happen as ships circulate weekly among the islands as well as those moving between the mainland and the islands. Additionally, it is necessary to understand what invasive species present on the coast of South America and/or peripheral islands in the Pacific could, in theory, reach the Archipelago, given the oceanic connectivity in the Eastern Tropical Pacific. It is a high priority to continue long-term monitoring, to keep track of non-native species established in the RMG, to determine whether their abundance and/or distribution change. The information generated by monitoring will enable us to establish a program for detection and early management, to forestall a possible invasion.

- **Priority:** High

- **Research location:** Galapagos Islands

- **Resources required:** Research divers, marine transport, diving gear and field materials

- **Duration of the research:** Indefinite

- **Institutional collaboration:** CDF, DGNP, ABG

- **Funding:** This activity is funded by the Galapagos Conservancy up to June 2015. Approximately $30,000 is required to hire personnel.

1.4 Installing and analyzing settling plates

Many marine species have larval phases in their development, which can facilitate their dispersal. When they end their larval stage, they look for substrates to settle and continue on to their next phase of development. To be able to effectively monitor and detect early on when invasive marine species may have arrived, we propose to install settling plates (made of PVC, measuring 100cm2) in ports located on the populated islands. The protocols of the Smithsonian Environmental Research Center (SERC) will be used to ensure replicability and comparability with other sites the world over. The PVC plates have been tested and have proven to yield successful results.

1.4.1 In the main harbors in the RMG

- **Priority:** High
- **Research location:** Galapagos Islands (Santa Cruz, San Cristóbal, Isabela, Floreana, and Baltra)
- **Resources required:** Research divers, marine transport, diving gear, settling plates, materials to install the plates, and laboratory materials.
- **Duration of the research:** 1-3 years
- **Institutional collaboration:** CDF, DGNP, ABG, SERC, STRI
- **Funding:** This activity is partially funded by the Galapagos Conservancy and by materials donated by the Smithsonian Environmental Research Center (SERC). Funding is required to purchase more materials to install and analyze the settling plates, approximately $10,000.

1.4.2 At key sites around the RMG

- **Priority:** High
- **Research location:** Galapagos Islands
- **Resources required:** Research divers, marine transport, diving gear, settling plates, materials to install the places, and laboratory materials.
- **Duration of the research:** 1-3 years
- **Institutional collaboration:** CDF, DGNP, ABG, SERC, STRI
- **Funding:** This activity is not funded. It can be completed in combination with activities 1.1 and 1.3, by providing the materials (approximately $10,000).

1.4.3 Installing and analyzing settling plates in harbors on the Ecuadorian mainland

The settling plates will be set up in several harbors on the Ecuadorian mainland

- **Priority:** High
- **Research location:** Ports of Manta, Esmeraldas, Salinas and Guayaquil on the Ecuadorian mainland.
- **Resources required:** Research divers, marine transport, diving gear, settling plates, materials to install the plates, and laboratory materials.
- **Duration of the research:** 1-3 years
- **Institutional collaboration:** CDF, ABG, Under-secretariat of Marine and Coastal Management, Technical Secretariat of the Sea
- **Funding:** This activity is not funded. It will require materials and transport to the Ecuadorian mainland and between the several ports, and per diems for two persons, approximately $30,000.

1.5 Training workshop on identifying species on settling plates

A workshop will be held with experts from the Smithsonian Environmental Research Center and the Smithsonian Tropical Research Institute on how to identify organisms on settling plates retrieved from the docks.

- **Priority:** High
- **Research location:** Galapagos Islands
- **Resources required:** International airfares and per diems for experts from SERC/STRI, laboratory materials.
- **Duration of the research:** 1 month
- **Institutional collaboration:** CDF, DPNG, ABG, SERC, STRI
- **Funding:** This activity is not funded. It will require $20,000 to bring experts from abroad and technicians from institutions on the mainland.

1.6 Identifying samples taken in Galapagos during the workshop in February 2015

One of the workshop's activities was a field trip to gather samples of species. These samples were sent to James Carlton's laboratory at Williams College so the experts who attended the workshop can identify the species encountered. This will help determine which non-native species are found in the RMG.

- **Priority:** High
- **Research location:** USA, Panama
- **Resources required:** Time from international experts, laboratory materials, genetic analysis, sending of samples.
- **Duration of the research:** 1 year
- **Institutional collaboration:** Williams College, SERC, STRI

- **Funding:** These samples will be analyzed by the workshop's experts as a counterpart contribution to the project.

2. How could non-native species get to the RMG?

Marine organisms need mechanisms or vectors to move from one region to another. There are several categories of vectors, including the following: ship hulls, ballast water, aquaculture, marine garbage, ocean currents, and migratory species. That is why a detailed study is necessary to ascertain which vectors are the likeliest to transfer possibly invasive species to the RMG.

2.1 Analysis of maritime traffic flow and routes entering the RMG

Biological invasions by plants, animals and pathogens have increased globally in recent years, because of growing commercial, recreational and tourist maritime traffic. In the RMG, there are different types of vessels, pursuing different activities, plus vessels traveling between the RMG and the Ecuadorian mainland or international harbors. This will be based on existing studies.

- **Priority:** High
- **Research location:** Galapagos Islands
- **Resources required:** Researchers
- **Duration of the research:** 1-3 years
- **Institutional collaboration:** CDF, DPNG, ABG, MTOP, DIRNEA
- **Funding:** This activity is funded by the Galapagos Conservancy up to June 2015. Approximately $20,000 is needed to hire personnel.

2.2 Risk analysis of ships entering the RMG as vectors of marine species

The number of ships and the frequency of their trips have changed greatly in recent years. An analysis of ships and the inspections they must undergo to prevent non-native species from entering the RMG can determine what species are getting into the RMG.

- **Priority:** High
- **Research location:** Galapagos Islands
- **Resources required:** Researchers
- **Duration of the research:** 1-3 years
- **Institutional collaboration:** CDF, DPNG, ABG, MTOP, WILDAID
- **Funding:** This activity is not funded. It will require approximately $20,000 to hire personnel.

2.3 Analysis of currents in the RMG and the Eastern Tropical Pacific

The marine ecosystem of Galapagos features a number of different biological communities, due to the confluence of currents and their connectivity with the Eastern Tropical Pacific (ETP). A study to identify where they come from and where these currents go, which might transport non-native species, and during which seasons of the year, is essential to find key sites in the RMG where an invasion might happen, such as Cromwell's Sub-surface Current.

- **Priority:** High
- **Research location:** Galapagos Islands
- **Resources required:** Researchers
- **Duration of the research:** 1-3 years
- **Institutional collaboration:** CDF, CI, INOCAR
- **Funding:** This activity is not funded. It will require approximately $20,000 to hire personnel.

2.4 Identify possible invasions because of climate change and/or "El Niño"

The Archipelago has witnessed climate variations for centuries, such as the El Niño phenomenon, which brings surface currents and warm water to the Islands, caused by the trade winds. Establishing a predictive model to identify the likelihood of new species with invasive characteristics arriving in Galapagos due to unforeseen climate effects will help reinforce prevention and early warning protocols. Each species has a range of tolerance for temperature, salinity, nutrients, etc. and types of habitat and substrate where they tend to establish themselves. These 'profiles' of what we know about the RMG biophysical situation can be considered, to identify the most sensitive areas for possible invasions within the Archipelago.

- **Priority:** High
- **Research location:** Galapagos Islands
- **Resources required:** Researchers
- **Duration of the research:** 1-3 years
- **Institutional collaboration:** CDF, CI, INOCAR
- **Funding:** This activity is not funded. It will require approximately $20,000 to hire personnel.

2.5 Analysis of garbage in the RMG

Marine garbage can threaten remote islands around the world, such as the Galapagos Islands. Non-native species can adhere to floating wastes in the sea and be carried to different regions. A good example is the “ghost” nets that are lost and then carried to different parts of the world by ocean currents. Another is the fish aggregating devices left behind by illegal fishing boats.

- **Priority:** Medium.
- **Research location:** Galapagos Islands
- **Resources required:** Researchers
- **Duration of the research:** 1-3 years
- **Institutional collaboration:** USFQ
- **Funding:** This activity will be done by USFQ with a PhD student.

2.6 Modelling dispersal of non-native species toward the RMG

The workshop included two experts from the University of Waikato in New Zealand, who have created a model that can predict the dispersal of a species from one region to another, using marine traffic and the IUCN’s bio-regions. This tool could be used to predict what species might get to the RMG, which would help formulate a prevention plan.

- **Priority:** High
- **Research location:** New Zealand, Galapagos Islands
- **Resources required:** Researchers
- **Duration of the research:** 1-3 years
- **Institutional collaboration:** University of Waikato, University of Dundee, CDF
- **Funding:** PhD candidates from Dundee University and Charles Darwin University will work with experts from Waikato University.

2.7 Analysis of connectivity in the Eastern Tropical Pacific

Developing a model for ocean circulation to see the connectivity between the Galapagos Islands and the Eastern Tropical Pacific will help determine the risks of species dispersal. This tool will be able to predict invasions from all areas of the Eastern Tropical Pacific and propose a regulatory framework and protocols to prevent introduction of marine invasive species.

- **Priority:** High
- **Research location:** Galapagos Islands, USA, United Kingdom
- **Resources required:** Researchers
- **Duration of the research:** 1-3 years
- **Institutional collaboration:** CDF, University of Southampton, University of Dundee, Conservation International

- **Funding:** This activity is not funded. It will require approximately $20,000 to hire personnel.

2.8 Risk analysis for petroleum ships coming from the mainland to the RMG

Tankers distributing petroleum to the Galapagos Islands navigate along the whole Ecuadorian Coast and are not inspected before entering the RMG. An analysis of their routes must be studied, with protocols for hull inspection and ballast water analysis.

- **Priority:** High
- **Research location:** Galapagos Islands, mainland Ecuador
- **Resources required:** Researchers
- **Duration of the research:** 1 year
- **Institutional collaboration:** CDF, MTOP, DIRNEA, ABG
- **Funding:** This activity is not funded. It will require approximately $10,000 to hire personnel.

3. What are the most efficient measures to reduce the risk of introducing and/or establishing marine species in the Archipelago?

Conducting an analysis of risks/benefits of having a centralized harbor for the Archipelago. Developing protocols to monitor harbors and vessels for early detection based on the findings from research under items 1 and 2. Developing contingency plans for high-risk invaders, based on research findings from items 1 and 2, and developing a strategic plan.

3.1 Implementing regulations for washing diving and snorkeling gear between visitor sites in the RMG

In the RMG, there are 169 visitor sites that are visited daily by tourist vessels, which carry out various activities, including diving, snorkeling and kayaking. These marine activities pose a risk because they might transmit species from one visitor site to another.

- **Priority:** Medium.
- **Research location:** Galapagos Islands
- **Resources required:** Researchers, outreach materials
- **Duration of the research:** 6 months
- **Institutional collaboration:** CDF, DPNG, ABG

- **Funding:** This activity is not funded. It will require approximately $5,000 for outreach materials.

3.2 Plan to prevent non-native species from entering the RMG (e.g., Carijoa riisei)

The risks associated with introduction of marine invasive species must be considered: possible entry vectors, probability of establishing themselves, and their negative effects. The risk of potential propagation of marine invasive species is quite real in the RMG, due to the large volume of maritime traffic in the Archipelago and the connectivity with the Ecuadorian mainland and other countries in the Eastern Tropical Pacific.

- **Priority:** High
- **Research location:** Ecuadorian mainland.
- **Resources required:** Researchers, outreach materials
- **Duration of the research:** 1 year
- **Institutional collaboration:** CDF, ABG, DPNG, Nazca, Under-secretariat of Marine and Coastal Management, Technical Secretariat of the Sea
- **Funding:** This activity is not funded. It will require approximately $10,000 for outreach materials and personnel.

3.3 What are the resolutions for discharging ballast water in the RMG and how can they be improved to reduce risks of introducing marine invasive species?

The Ministry of Transport and Public Works, through the Under-Secretariat of Harbors and Maritime and Riverway Transport, in coordination with the Directorate of the Galapagos National Park (DGNP), have created the Ecuador Task Force. This group will establish a nationwide strategy to assess the problem of non-native species introduced by water from international shipping.

- **Priority:** Medium
- **Research location:** Galapagos Islands, Ecuadorian mainland
- **Resources required:** Researchers
- **Duration of the research:** 1 year
- **Institutional collaboration:** CDF, DPNG, MTOP, Under-secretariat of Marine and Coastal Management, Technical Secretariat of the Sea
- **Funding:** This activity is not funded. Approximately $5,000 will be required.

3.4 How would an Emergency Operations Committee (COE) work for marine invasive species in the RMG?

Prevention, early detection and rapid response are essential to manage marine invasive species. **Prevention and early detection are the best ways to control entering marine invasive species**, but if an invasion occurs, there must be protocols for rapid response. Therefore, it is essential to create a COECOE-EIM (EMERGENCY OPERATIONS COMMITTEE FOR MARINE INVASIVE SPECIES).

3.4.1 Creating an Emergency OperationsCommittee (COE-EIM) for rapid response in the event that a non-native species enters the RMG

Creating a COE-EIM for marine invasive species is a high priority. This committee must be created among all relevant institutions and its protocols must be decided and approved among all relevant parties. Each institution must appoint a delegate, to act when the MAE decides.

- **Priority:** High
- **Research location:** Galapagos Islands
- **Resources required:** Researchers
- **Duration of the research:** 2 years
- **Institutional collaboration:** CDF, DPNG, ABG, DIRNEA
- **Funding:** This activity is not funded. Approximately $5,000 will be required.

3.5 What is the most efficient way to inspect ships' hulls to detect non-native species?

Vessels can bring organisms fouling their hulls, propellers, anchors, chains, water intakes, etc. A new species can settle when the fouling organisms come into contact with structures at the port of arrival or when eggs/larvae are released in their water. Then they can settle in ports and spread to nearby areas. It is crucial to inspect vessels' hulls using a meticulous inspection methodology.

3.5.1 Training workshop for inspecting ships' hulls and gathering samples

Holding a training workshop for ship inspection personnel will prepare inspectors to use a standard methodology. This training will enable technical staff to improve their search techniques for all parts of vessels, taking photographs, videos and samples as required.

- **Priority:** High
- **Research location:** Galapagos Islands
- **Resources required:** Researchers and Inspectors
- **Duration of the research:** 6 months
- **Institutional collaboration:** CDF, ABG, DPNG
- **Funding:** This activity is not funded. Approximately $5,000 will be required.

3.6 Creating vessel hull inspection protocols

Vessel hull inspection protocols must be created and discussed among all institutions with the mandate to inspect vessel hulls.

- **Priority:** High
- **Research location:** Galapagos Islands
- **Resources required:** Researchers and Inspectors
- **Duration of the research:** 1 year
- **Institutional collaboration:** CDF, ABG, DPNG, WILDAID
- **Funding:** This activity is not funded. Approximately $5,000 will be required.

4. What is the risk of Carijoa riisei getting to the RMG and how can we prevent it?

Snowflake coral, *Carijoa riisei* – one of the worst marine invasive species – has been reported on mainland Ecuador continental and on Malpelo Island in Colombia. The Nazca Marine Research Institute has received reports of this coral rapidly expanding along the Ecuadorian coastline, posing the risk for this species to reach the RMG.

4.1 Monitoring Carijoa riisei on Ecuador's Coast to map this species' distribution

It is very important to study the distribution of *Carijoa riisei* to learn this species' degree of invasion on Ecuador's coastline and determine the risk posed by this species for the RMG.

- **Priority:** High
- **Research location:** Ecuadorian mainland.
- **Resources required:** Research divers, marine transport, diving gear and field materials
- **Duration of the research:** 1 year
- **Institutional collaboration:** CDF, ABG, Nazca, Under-secretariat of Marine and Coastal Management, Technical Secretariat of the Sea
- **Funding:** This activity is not funded. This will require $50,000 to hire personnel, dive boats and equipment.

4.2 Investigating mechanisms to control Carijoa riisei on the Ecuadorian mainland

After ascertaining the distribution of *Carijoa riisei,* strategies can be set to manage this species, determining the necessary control measures. Depending on the degree of invasion, the process may be long, and different methods of eradication should be considered.

- **Priority:** High
- **Research location:** Ecuadorian mainland.
- **Resources required:** Researchers
- **Duration of the research:** 1 year
- **Institutional collaboration:** CDF, ABG, Nazca, Under-secretariat of Marine and Coastal Management, Technical Secretariat of the Sea
- **Funding:** This activity is not funded. It will require approximately $50,000 to organize meetings and mobilize personnel. This amount could increase depending on the control measures to be implemented.

7. Recommendations

- Plan to prevent non-native species from entering the RMG: This is a serious problem not only for Ecuador. If we are to prevent non-native species from invading Ecuadorian ecosystems, rules or commitments must be established with neighboring countries (Peru & Colombia). If an invasive species is on the coast of Colombia, it is quite likely that it will spread to Ecuador in several ways, and then to the Galapagos.
- ECUADOR TASK FORCE (GTE). A symposium held on the mainland to establish the laws controlling Globallast has recommended holding information meetings to plan and implement commitments that each institution on the GTE may undertake.
- A procedural manual for the different stages involved in marine invasive species issues will range from vectors to existing management strategies to deal with an established species and a newly-introduced one.
- WildAid commits its support to prepare protocols and training ABG staff in inspecting to prevent marine species from entering.
- Mechanisms to control *Carijoa riisei*: An "Invasive Species Action Group" could be created to be trained to eradicate these species, tapping experiences from countries where this species has invaded.
- Vessel hull inspection: Establish work groups in each harbor so inter-disciplinary personnel performs the inspection and identifies the species, in addition to making relevant decisions regarding species that are present and potentially invasive.
- Installing settling plates on the mainland: Training personnel working with mainland institutions would be the best option, thereby generating a need in their annual operating plans, allocating funds and purchasing their own equipment and materials, making this a long-term activity over time.
- It is important to monitor inter-tidal zones, which are among the first localities where invasive species may settle.
- The key issue with marine invasive species is to assess the damage they are causing to native biodiversity and ecosystem alteration.

- Intensify control over anthropogenic activities involved in shipping traffic.
- Get each tourism company or institution to have fresh water pools, chlorinated, to wash equipment used for tourist activities, to prevent transmission of species from one visitor site to another.
- Support research regarding this issue and encourage citizen awareness.
- Ecuadorian Navy vessels visiting the islands may be significant vectors transporting outside species. It is recommended for the Navy to carry out protocols to clean and inspect their hulls before entering the RMG.
- Publicity and education campaigns must accompany the research.

Appendix VIII

Plan de BioseguridadMarina para la Copa Galápagos 2014

Manejo de cascos y estructuras para prevenir la introducción de especies no-nativas a la Reserva Marina de Galápagos

Elaborado por: Inti Keith yPriscilla C. Martínez
Setiembre 2014
Puerto Ayora, Santa Cruz, Galápagos
Fundación Charles Darwin (FCD)

Documento elaborado por La Fundación Charles Darwin (FCD), organización internacional sin fines de lucro con base en Galápagos, cuya misión es "*Proveer los conocimientos y el apoyo para asegurar la conservación de la biodiversidad en el Archipiélago de Galápagosa través de la investigación científica y acciones complementarias*" La FCD desea destacar el rol fundamental desemepeñado por nuetros socios y colaboradores: La Direcion del Parque Nacional Galapagos(DPNG), Agencia de Regulacion y Control de Bioseguridad y Cuarentena para Galapagos (ABG), La Direcion Nacional de Espacios Acuaticos (DIGMER), y el Instituto Oceanografico de la Armada (INOCAR)

Tabla de contenido

1. Introducción

Las invasiones biológicas de plantas, animales o patógenos, han incrementado globalmente en los últimos años, debido al creciente tráfico marítimo comercial, recreacional y de turismo. Las invasiones se producen cuando los organismos son transportados accidental o intencionalmente de una región a otra y después de su arribo logran establecerse y propagarse. Estos organismos invasores compiten por espacio, desplazan a especies nativas y cambian poblaciones naturales. Por ello, representan una alta amenaza que afecta a la biodiversidad, recursos naturales, economía y salud humana.

Los ecosistemas marinos de Galápagos albergan comunidades biológicas muy particulares, con una alta incidencia de especies endémicas. Estas carecen de mecanismos de defensa ante las especies exóticas, con las cuales no han evolucionado. Las especies de Galápagos ya han mostrado vulnerabilidad a las condiciones de variabilidad climática extrema durante eventos fuertes de El Niño y/o la Niña. Si a estos factores, se añade la introducción de especies exóticas, aumentan los riesgos de perdida biodiversidad en el Archipiélago y el desafío propio de control y manejo.

Con estos antecedentes y considerando el riesgo incalculable que presentan las especies invasoras marinas para la conservación de los ecosistemas y especies de la Reserva Marina de Galápagos (RMG) a largo plazo, necesitamos minimizar los impactos negativos de las especies invasoras sobre la biodiversidad marina, servicios de los ecosistemas y la salud de la RMG, a través de un Plan de Bioseguridad Marina.

Este documento tiene como objetivo orientar a los propietarios, operadores e inspectores de las áreas de marinería del Salinas Yacht Club, sobre los peligros que pueden causar las especies no-nativas cuando son transportadas en los cascos de embarcaciones fuera de su área de distribución natural, y prevenir que esto suceda. El documento también analiza y clasifica de una forma, muy sencilla los riesgos que existen de que una especie sea transportada de una región a otra.

El termino bioseguridad en el contexto de este documento, significa adoptar medidas de prevención con el fin de minimizar la introducción o propagación de especies no-nativas. El movimiento de embarcaciones, estructuras o equipos puede causar tanto la introducción de una nueva especie no-nativa, como también, la propagación de una especie no nativa ya establecida en un sitio, a una ubicación nueva.

Cuando una especie no-nativa es introducida a un área nueva y amenaza la biodiversidad, la salud humana o la economía, se la conoce como una especie invasora. Se conoce muy poco sobre los impactos que pueden causar a largo plazo las especies no-nativas invasoras cuando son llevadas e/o introducidas a una nueva región, por lo cual es muy importante usar técnicas de manejo para prevenir el arribo y la propagación de estas especies porque una vez que estas especies se asientan, reproducen e invaden, son casi imposibles de erradicar.

Algunas especies con alto potencial invasor ya se encuentran establecidas en la Reserva Marina de Galápagos (RMG) según registros históricos y monitoreos submareales dirigidos específicamente a especies invasoras marinas. Tal es el caso de las algas *Caulerpa racemosa* y *Asparagopsis taxiformis,* que ya se encuentran establecidas y tienen una distribución amplia en la RMG. Estas especies están siendo monitoreadas, pero existe el gran riesgo de que arriben otras especies que aún no se encuentran en la RMG, como es el caso del octocoral copo de nieve *Carijoa riisei,* que está reportado en Ecuador continental (Esmeraldas, Manabí y Santa Elena) y en la Isla Malpelo en Colombia. El Instituto Nazca de Investigaciones Marinas - tiene reportes de la rápida expansión que se ha visto en la costa Ecuatoriana y el riesgo que existe que de que esta especie llegue a la RMG. Listas completas de especies no-nativas ya establecidas en la RMG y especies no-nativas potencialmente invasoras se pueden encontrar en el (Anexo I).

2. Conceptos Claves: Definición de Riesgo

El riesgo de una potencial propagación de especies invasoras marinas es muy real en Galápagos, debido al alto porcentaje de barcos que circulan en la RMG, la diversidad de hábitats y los patrones oceanográficos, y su conectividad por las corrientes y eventos climáticos extremos como El Niño y/o la Niña. Un riesgo se define como la posibilidad de que se produzca un daño o cambio debido a eventos naturales o a eventos creados por el hombre. Los riesgos asociados con la introducción de especies invasoras marinas tienen que ser considerados tomando en cuenta los vectores de ingreso, la probabilidad de que pueda establecerse exitosamente y el potencial daño que podría tener dicha introducción.

A continuación las definiciones de la terminología correcta usada para este proyecto.

Especies Endémicas: Especies que están restringidas a un área de distribución muy concreta y fuera de ésta no se las encuentra.

Especies Nativas o Indígenas: Especies que ocurren dentro de su área de distribución natural, sin intervención directa o indirecta del ser humano.

Especies Criptogenicas: Especies de origen desconocido, no se sabe si son nativas o introducidas, debido a la falta de información sobre la especie.

Especies No Nativas, No autóctonas, Exóticas: Especies que han sido movilizadas por acción humana, fuera de su área de distribución natural, donde son capaces de sobrevivir y establecerse.

Especies Invasoras: Especies que causan o tienen el potencial para causar daño al medio ambiente, la economía o la salud humana.

Especies Potencialmente Invasoras: Especies Introducidas que podrían convertirse en invasoras y en especial si han demostrado este carácter, en otros países con condiciones ecológicas semejantes a las de la RMG.

Introducción Intencional: Cuando el traslado de la especie fuera de su área natural es intencional. (No Autorizadas y Autorizadas)

Introducción No Intencional: Cuando la especie utiliza a los seres humanos o sus sistemas de distribución como vectores de dispersión fuera de su área natural

Arribos Naturales: Se da a través de migraciones o empleando como vector especies migratorias que viajan por los océanos del mundo (ballenas, tortugas) y por modificaciones en las condiciones ambientales en determinadas áreas. El cambio climático global es una de las principales causas recientes de la expansión del ámbito de distribución de algunas especies.

3. La importancia de un Plan de bioseguridad

Todos nosotros dependemos de un entorno marino sano para prosperar. Sin embargo, los daños al medio ambiente pueden afectar la biodiversidad y dar lugar a enormes pérdidas financieras a nivel local -operadores turísticos y/o comerciales o regional. Un plan de bioseguridad eficaz puede ayudar a mejorar estos riesgos.

El valor de un ambiente marino sano ha sido ampliamente aceptado y entendido desde hace algún tiempo. Lo que está cambiando es que cada vez somos más conscientes de que la biodiversidad de nuestros mares nos proporciona una amplia gama de beneficios llamados servicios ecosistémicos de los cuales dependen nuestras vidas y medios de subsistencia. Las especies no-nativas invasoras ponen en peligro los ecosistemas marinos. Es por ello que el Ministerio del Ambiente, con la implementación del modelo el Buen Vivir, busca el fortalecimiento de un desarrollo sostenible como es la producción y consumo sostenible, contaminación atmosférica, cambio climático y la protección de la biodiversidad.

Por todo lo antes mencionado es importante tener un plan de bioseguridad para minimizar la introducción o propagación de especies no-nativas invasoras a un puerto; de esta manera no habrá costos de erradicación, los cuales pueden ser muy costosos. Por otro lado, también nos sirve de herramienta para concientizar al público local, nacional y regional mostrar a los visitantes cómo se está respondiendo responsablemente a una seria amenaza ambiental, como son las especies no-nativas invasoras.

4. Formulando un Plan de Bioseguridad

El objetivo principal de este plan es prevenir la introducción de especies no-nativas a la Reserva Marina de Galápagos.

Como primer paso, es importante conocer bien el sitio desde el cual van a salir las embarcaciones, en este caso, la marina del Salinas Yacht Club. Un buen conocimiento del lugar ayuda a producir un plan mucho más eficaz. A continuación se deberá responder una serie de preguntas sobre el sitio de estudio.

1) ¿Cual es la salinidad del agua?

La mayoría de animales y algas marinas no pueden tolerar agua dulce por largos periodos de tiempo. Lo cual significa que si existe una vertiente de agua dulce en el sitio, la cual reduce la salinidad esto hará que el área sea menos hospitalaria para especies no-nativas. El mayor riesgo existe cuando el agua es totalmente salina.

2) ¿Cuántas estructuras hechas por el hombre se encuentran en el agua?

El riesgo de introducción y establecimiento de especies no-nativas invasoras se incrementa por la presencia de estructuras artificiales, por ejemplo, rampas de concreto, muelles flotantes, cascos, cadenas y boyas ya que estas especies típicamente prefieren asentarse en las estructuras hechas por el hombre en lugar de las superficies naturales. Cualquier estructura que ha estado en el agua durante unas pocas semanas, sobre todo en los meses de agua caliente y sin pintura anti-fouling estaría en riesgo.

3) Ya existen especies no-nativas en el sitio?

Es muy probable que especies no-nativas ya estén presentes en los alrededores del Salinas Yacht Club, así que el plan de bioseguridad deberá concentrarse en reducir el riesgo de introducir nuevas especies no-nativas a este sitio, y a su vez, considerar la mejor manera de prevenir que la especies no-nativas presentes se conviertan en invasoras, o que sean trasladadas a otros lugares.

Si existen registros de especies del área de estudio, estos deben ser tomados en cuenta en el plan de bioseguridad. Sin embargo, en el caso de no tener evidencia de que existan especies no-nativas en el área, se deberá seguir el principio de precaución. Esto es, asumir que estas especias podrían estar presentes y actuar como si lo estuvieran.

Además de pensar en el sitio de estudio, las estructuras fijas y las especies no-nativas que ya están presentes, también es importante considerar la forma en que las especies no-nativas pueden ser introducidas. ¿Cuáles son los movimientos de las embarcaciones y equipos dentro y alrededor del sitio?

Es importante contar con toda la información de la embarcación, en el (Anexo II) se encuentra un formulario de datos sobre embarcaciones, este debe ser llenado en conjunto con el análisis de riesgo.

A continuación se deberá responder una serie de preguntas sobre las actividades con mayor riesgo de introducir una especie no-nativa:

- **¿Cómo se evalúa el Riesgo?**

La manera de evaluar si la respuesta a cada pregunta es de un nivel de riesgo Alto, Medio o Bajo es la respuesta de cada pregunta. Por ejemplo, ¿acaba de llegar la embarcación de un puerto lejano? si la respuesta es SI entonces es de Alto riesgo pero si la embarcación llego de un puerto cercano es de Medio o Bajo riesgo. Otro ejemplo ¿En las superficies sumergibles visibles de la embarcación se encuentran organismos? si la respuesta es SI entonces es Alto riesgo, si la respuesta es que el casco tiene algunos organismos significa que es de Medio riesgo y si solo tiene algunos organismos o ninguno es de Bajo riesgo. En caso de que el inspector no esté seguro de alguna pregunta, es recomendable optar por la respuesta de Alto riesgo para prevenir la introducción de especies no-nativas.

	ALTO	MEDIO	BAJO
1. ¿Acaba de llegar la embarcación de un puerto lejano?			
2. ¿ La embarcación ha tenido un recubrimiento de pintura anti-fouling dentro de los últimos 12 meses?			
3. ¿Todas las superficies sumergibles visibles de la embarcación están libres de bio-fouling?			
4. ¿En las superficies sumergibles visibles de la embarcación se encuentran organismos?			
5. ¿La embarcación tiene algas y/o animales adheridos a las partes visibles del casco/timón/ hélice?			
6. ¿La embarcación acaba de llegar de otro país o región con condiciones ambientales similares? (por ejemplo, la temperatura del agua)			
7. ¿ La embarcación acaba de llegar de otro país o región donde se conoce la presencia de especies no-nativas?			
8. ¿ La embarcación pasa largos periodos de tiempo sin movilizarse?			
9. ¿ es una embarcación lenta? (por ejemplo, una barcaza)			
10. ¿Durante el buceo se detectaron organismos?			

El mayor riesgo para la introducción de una especie no-nativa ocurre cuando una embarcación (particularmente las que viajan a poca velocidad por ejemplo, las barcazas que llegan de otro país o región que tiene condiciones ambientales similares (por ejemplo, temperatura, salinidad). Muchas de estas embarcaciones arriban con una capa fina de alga verde, esto es de menor riesgo; las de mayor riesgo son las embarcaciones que llevan consigo como polizontes, especies adheridas a los cascos, hélices, o anclas.

También es importante observar los muelles o boyas donde se acoderan las embarcaciones.

	ALTO	MEDIO	BAJO
1. ¿ Se encuentran organismos en las superficies sumergibles visibles de los muelles?			
2. ¿ Se encuentran organismos en las superficies sumergibles visibles de las boyas?			
3. ¿ Se detectaron organismos durante el buceo?			

5. Manejo de embarcaciones y estructuras fijas

- Inspecciones a estructuras fijas y cascos

Las inspecciones se deberán hacer a todos los muelles y boyas donde estén amarradas o ancladas las embarcaciones. La inspección deberá empezar desde arriba de la línea de agua hasta el fondo marino. Esto puede ser hecho por dos grupos, uno en la superficie y uno buceando.

Se deberán hacer inspecciones a todas las embarcaciones que tienen contemplado viajar a las Islas Galápagos. Se deberá inspeccionar cuidadosamente el casco, hélice, timón, rejillas, ancla, cadena etc.

Se recolectará cualquier especie no-nativa para identificación en el laboratorio y en lo posible se tomará fotografías y video de las áreas inspeccionadas.

- Casco limpio/casco sucio

Una vez finalizada la inspección de las embarcaciones, el inspector será la autoridad máxima en conceder el permiso para continuar el viaje a las Islas Galápagos.

En caso de que una embarcación no cumpla con los requerimientos de tener el casco limpio antes de zarpar a Galápagos, esta embarcación tendrá la oportunidad de limpiar el casco y ser sujeta a otra inspección. El área de limpieza de casco será indicada por las autoridades portuarias y la Agencia de Regulación y Control de la Bioseguridad y Cuarentena para Galápagos.

6. Recomendaciones

- Reunir información sobre bioseguridad de las embarcaciones visitantes lo más pronto posible; incluyendo el puerto de origen y fecha de la última vez que se pintó el casco con anti-fouling y de la última vez que se limpió el casco.
- Tener un área especial, si es posible con agua dulce, para las embarcaciones que llegan de puertos lejanos.

- Llevar a cabo una inspección visual rápida de los cascos de las embarcaciones de alto riesgo.
- Proporcionar información sobre bioseguridad para permitir a los propietarios de las embarcaciones "autoevaluar" su riesgo.
- Pedir a los propietarios de las embarcaciones no botar agua de sentina o lastre.
- Proporcionar instalaciones 'de cuarentena', si es posible, para las embarcaciones que tengan que limpiar los cascos.
- En el caso de que la embarcación sea sacada del agua para hacer la limpieza usar una lona para recolectar raspados de casco y asegurar que estos no caigan al mar.

Anexo I

Tabla 1: Especies no-nativas invasoras establecidas en la RMG

Nombre científico	Nombre común
Cardisoma crassum	Cangrejo azul

Bugula neretina	Briozoo café
Pennaria disticha	Hidroide
Caulerpa racemosa var. occidentalis	Alga racimo de uva
Asparagopsis taxiformis	Plumero de mar
Acanthaster planci	Estrella espinosa

Tabla 2: Especies no-nativas invasoras marinas potencialmente peligrosas para la RMG

Nombre científico	**Nombre común**
Asteria amurensis	Estrella de mar del Pacifico Norte
Chthamalus proteus	Balano Caribeño
Mytilopsis sallei	Mejillón de rayas negras
Undaria pinnatifida	Laminaria de Japón "Wakame"
Carijoa riisei	Octocoral copo de nieve
Caulerpa racemosa var. cylindracea	Alga uva
Codium fragile ssp. tomentosum	Dedos verdes de mar
Asparagopsis armata	Plumero arponado
Gracilaria salicornia	Alga roja
Hypnea musciformis	Alga gancho
Acanthophora spicifera	Alga espinosa
Chama macerophylla	Joyero escamoso
Diadumene lineata	Anemona de mar naranja con rayas
Didemnum candidum	Didendum blanco
Haliclona caerulea	Esponja azul del caribe
Carcinus maenas	Cangrejo verde europeo
Lutjanus kasmira	Pargo de rayas azules
Pterois volitans	Pez león

Anexo II

Nombre de la embarcación	**Tipo de embarcación**	**Longitud (m)**	**Puerto de origen**

Fecha de arribo	**Fecha de inspección**	**Localidad de inspección**	**Método de inspección**

Ruta recorrida antes de arribo	**Tiempo de permanencia en este puerto (días)**

(%) Cobertura bio-incrustaciones en proa	**(%) Cobertura bio-incrustaciones en el centro del bote**	**(%) Cobertura bio-incrustaciones en la popa**
Especies:	**Especies:**	**Especies:**

(%) Cobertura bio-incrustaciones hélice/timón	**(%) Cobertura bio incrustaciones línea de flotación**	
Especies	**Especies**	

Observaciones: